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DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

DEVELOPMENT AND FIELD TESTS OF A SAMPLER FOR SUSPENDED SEDIMENT IN WAVE ACTION

TECHNICAL MEMORANDUM NO. 34

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MARCH 1953

FOREWORD

Part I of this paper presents the laboratory development of a suspended sediment sampler for use in and near the surf zone. Part II presents the results of preliminary field tests of the sampler in the surf zone near Mission Bay, California.

The sampler was developed in the Research Division of the Beach Erosion Board under the supervision of Joseph M. Caldwell, Chief of the Research Division. George M. Watts, author of report, carried out the testing program and analysis of results, assisted by others of the Research Division staff. At the time the report was prepared, the technical staff was under the general supervision of Colonel E. E. Gesler, President of the Board and R. O. Eaton, Chief Technical Assistant. The report was edited for publication by Albert C. Rayner, Chief, Project Development Division.

The field data were obtained by the Board's Engineering Division under the direction of Jay V. Hall, Jr., Chief of the Division, by Field Group No. 1 of which D. R. Forrest was Project Engineer and R. L. Harris, Chief of Field Operations. The field operation of the sampler was from Crystal Pier, located on Pacific Beach. Grateful acknowledgment is made to Mrs. Alice M. Doyle, owner of this pier, for her cooperation and donation of the facilities of the pier.

Although additional field tests are necessary to evaluate fully this type of suspended sediment sampler, the results obtained are believed to be of sufficient value to merit publication at this time. The opinions and conclusions expressed herein are not necessarily those of the Beach Erosion Board.

This paper is published under authority of Public Law 166, 79th Congress approved July 31, 1945.

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DEVELOPMENT AND FIELD TESTS OF A SAMPLER
FOR SUSPENDED SEDIMENT IN WAVE ACTION
by

George M. Watts
Hydraulic Engineer, Research Division
Beach Erosion Board, Corps of Engineers

PART I - LABORATORY DEVELOPMENT

INTRODUCTION

1. Purpose - Material transported along a coast as littoral drift consists, at least in part, of that which is lifted into suspension by the turbulent wave currents in and near the surf zone. Transport may also occur along or so near the bed that it cannot be considered as movement in suspension. A knowledge of the quantity and properties of material thrown into suspension by waves of various characteristics may be of importance in the fundamental understanding of material movement on and along sandy beaches. The generalized empirical procedures currently employed in computing material movement along beaches might be substantially aided by some tangible knowledge of the quantity of suspended material. The purpose of this study is to develop a mechanical sampler that will extract a representative sediment sample from a point above the bed where material is in suspension due to wave action.

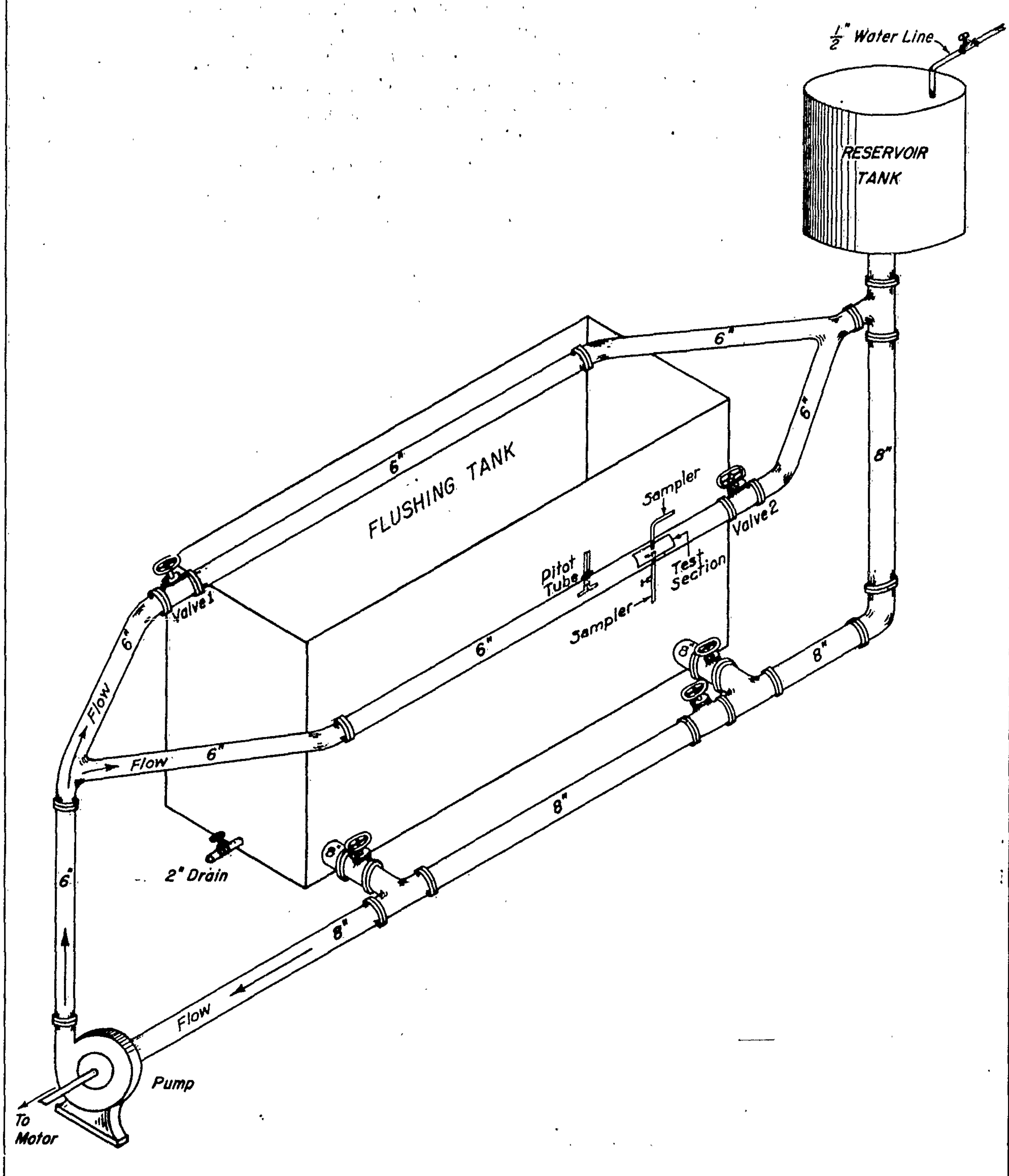
2. General Considerations - As far as is known, little progress has been made towards developing a sampler that will collect a representative sample of suspended sediment in connection with a study of wave action on sandy beaches. The quantity and character of suspended sediment in fluvial waters have been successfully investigated by the use of various types of samplers. In this type of work the sediment movement is essentially uni-directional, whereas in wave action the forces creating sediment movement are of a rapidly reversing or oscillating character. A review of the samplers developed for suspended sediment sampling in streams indicated that their successful adaptation to this particular problem would be doubtful, as they require an orientation into the current for successful operation. Such orientation is not practicable in wave action. In evaluating the type of sampler to be developed, consideration was given to the wave characteristics and their accompanying forces which cause the sand to be intermittently in suspension or on the bottom as successive wave crests pass over the bottom with instantaneous sediment concentrations varying rapidly at a given point. In view of the rapid variation in concentration it seemed advisable to develop a sampler that would collect a sample over an appreciable interval of time rather than an instantaneous sample. For this reason a suction or pump-type sampling technique appeared to be most

suitable, as a sample pumped from a selected point for an appreciable duration of time would be more representative of the concentration at this point than would a short-interval sample.

3. The most important feature that had to be investigated concerning a pump-type sampler was probably its reliability or accuracy in obtaining a representative sample from a suspension. The intake of the sampler had to be investigated as to orientation, shape, velocity of flow into the intake, and velocity of the fluid or fluid-sediment mixture passing the intake. As the general practice of orientating the intake nozzle into the flow, such as in uni-directional river flow, was not practicable in the case at hand due to the rapid reversals of flow direction inherent in oscillatory wave action, it was decided that a single intake positioned perpendicular to the bed or bottom plane would probably represent the best compromise, in that its efficiency would be essentially independent of the horizontal direction of flow. The purpose of this investigation being to develop a sampler for use in oscillatory wave action, it would have been desirable to test and calibrate the sampler in such wave action. As no means of creating an oscillatory water motion in which the sand concentration was known from point to point and from time to time appeared practicable, it was believed that a circulatory system which generated uni-directional velocities from zero to the maximum expected to be encountered in nature could be used in developing the sampler. The concentration of suspended material within the circulating system was to be flexible to the extent that the maximum expected concentration found in nature could be reproduced.

APPARATUS

4. Circulating System - Figure 1 is a diagramatic sketch of the circulating system designed for and employed in this study. A centrifugal pump with capacity of 2.55 cubic feet per second, driven by a 10-horse power motor, was utilized to circulate the suspension. By varying the speed of the pump motor and by manipulation of valves 1 and 2, a maximum flume velocity of 12.5 feet per second could be obtained through the test section. A diversion was installed upstream from valve 1. The diversion and operation of valves 1 and 2 permitted the adjustment of low flume velocities in the test section and high velocities in the remainder of the circulating system thereby insuring against the possibility of sediment settling out and clogging the system. The test section was located in a horizontal 16-foot length of 6-inch pipe between the diversion and valve 2. The sampling point was located 4 feet upstream from valve 2. An observation window was installed in the pipe for observing the suspension flow and specifically to insure the proper orientation of the intake nozzle. Facilities were made at the sampling point for entrance into either the top or bottom of the pipe. A pitot tube installed at a point 18 inches upstream from the test section was connected to a differential manometer equipped with a graduated scale. Velocity values were computed from the differential readings. The position of the pitot tube relative to the 6 inch pipe permitted measurements of velocity only in the vertical axis



SCHEMATIC DIAGRAM OF CIRCULATING SYSTEM

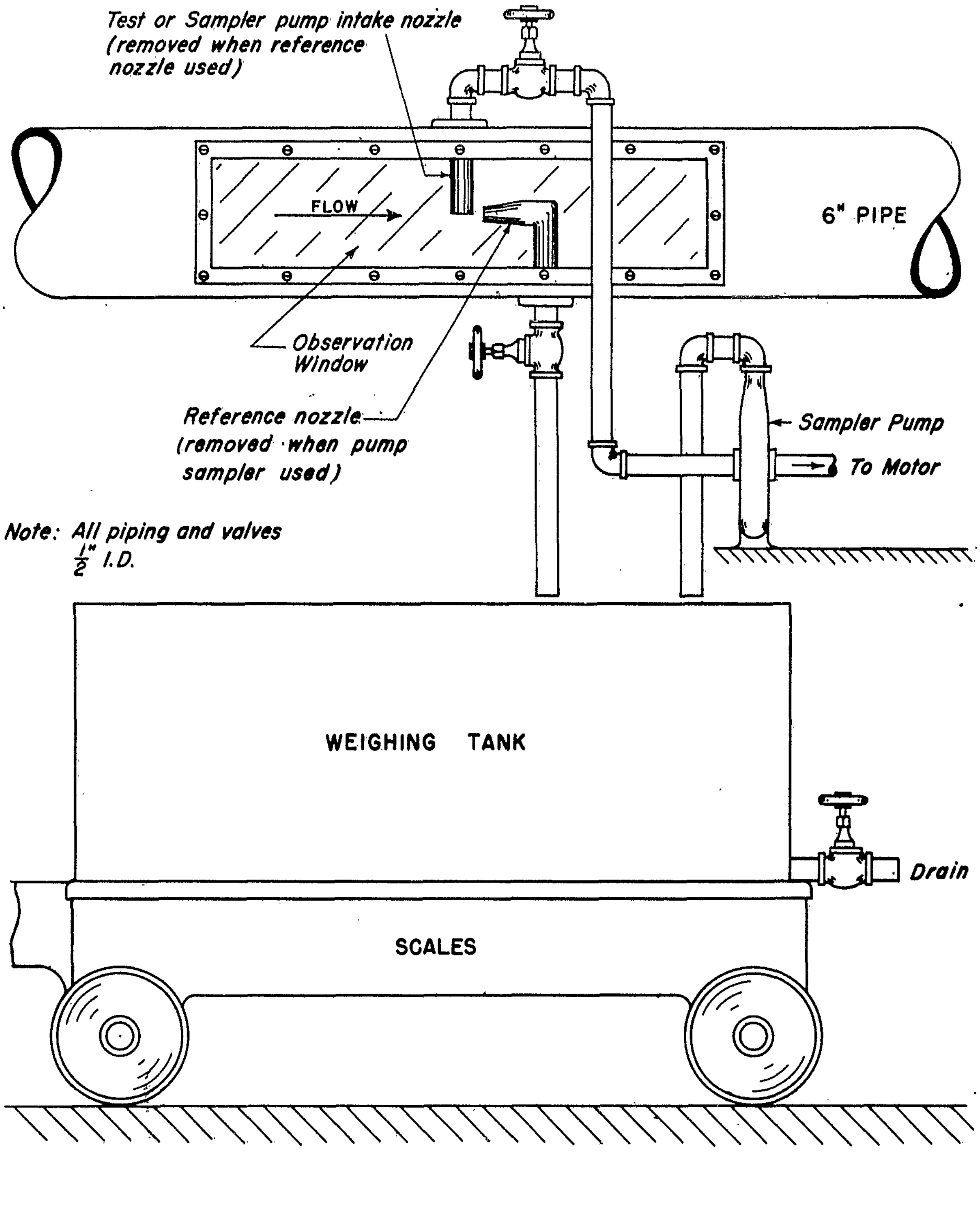
FIG. 1

of the pipe cross-section. A reservoir or head tank 3 feet in diameter and 4 feet high was installed in the system, the base of the tank being approximately 18 inches above the test section. The tank functioned as an escape for air in the circulating system, as a positive pressure control to the system, and an opening for replenishing the volume of water and sediment that was extracted in sampling. Experience in extracting samples gave an index on the rate at which the sediment and water should be returned to the system. The replenishment was done manually since the fairly large capacity of the entire system offset any error that might result from non-uniform return feeding of the sediment and water. A bypass pipe system on the return flow to the pump and a flushing tank were utilized to flush the circulating system when changes in the sediment characteristic and concentrations were desired. The cross-sectional area and length of the flushing tank between the flushing intake and discharge were sufficient to decrease the velocity in the tank, thereby allowing the sediment to settle out. A drainage valve was installed in the flushing tank to drain the system, clean the sediment out of the tank, and repeat the flushing cycle if desired.

5. Sampling Nozzles and Pump - The arrangement of sampling nozzles and pump in the circulating system is shown schematically in Figure 2. The beveled 1/2-inch internal diameter nozzle (known as the reference nozzle) was inserted when in use into the observation station from the bottom of the pipe and adjusted so that the nozzle opening faced upstream. This nozzle was used to extract samples from the circulating system at a specific point in the vertical axis of the test section. These samples were extracted at a nozzle intake velocity equal to the flume velocity; since they passed into the intake without changing direction or velocity, they were considered to be reference samples which closely defined the sediment concentration at the sampling point.

6. Test nozzles of various sizes connected to the sampler pump were inserted in the top of the pipe at the sampling station and utilized to extract samples by actual suction. The intake of the test nozzle was always placed perpendicular to the flow. All nozzles used were slightly rounded or beveled at the intake in order to minimize flow disturbances which a sharp edge might create. In order to extract samples at a desired nozzle velocity, the test nozzle was connected to a single stage centrifugal pump, with capacity of 30 gallon per minute. Each sample taken by the pump was discharged into a tank mounted on scales and the sediment concentrations computed therefrom. Intake nozzle velocities were determined from the durations of the operation.

7. Sand Characteristics - A medium sand with a typical size distribution as found on natural beaches was believed to be the most representative sediment for use in developing the sampler. The size distribution, as determined by mechanical analysis, is shown in Figure 3. The median size was approximately 0.53 millimeter.



SCHEMATIC ILLUSTRATION OF SAMPLING APPARATUS

FIG. 2

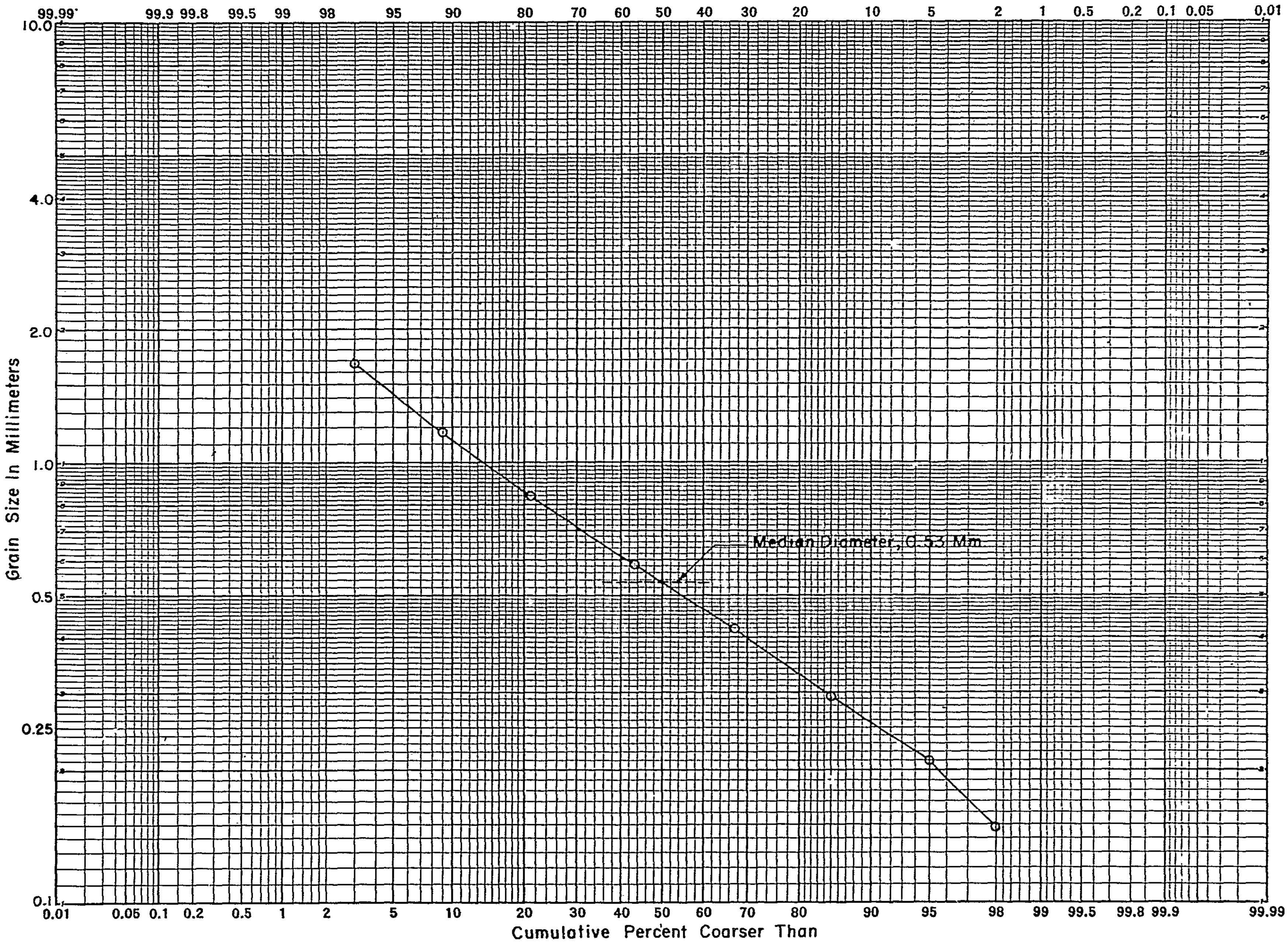


FIG. 3. MECHANICAL ANALYSIS OF SAND USED IN TESTS

TEST PROCEDURE

8. Flume Velocity Calibration - By manipulation of valves 1 and 2 in the circulating system (Figure 1) and regulating the speed of the circulating pump, selected velocities could be obtained in the test section. Velocity distributions for various valve-pump load settings are shown on Figure 4. It will be noted that almost all magnitudes of velocities up to approximately 12.5 feet per second could be produced in the test section. Flows below 2 feet per second were not tested, as most of the sand settled out of suspension at those velocities. In general the water temperature was approximately 68° F, which with a 6-inch pipe, indicated a Reynolds number in the turbulent region for all tests. O'Brien's* definition of critical velocity is

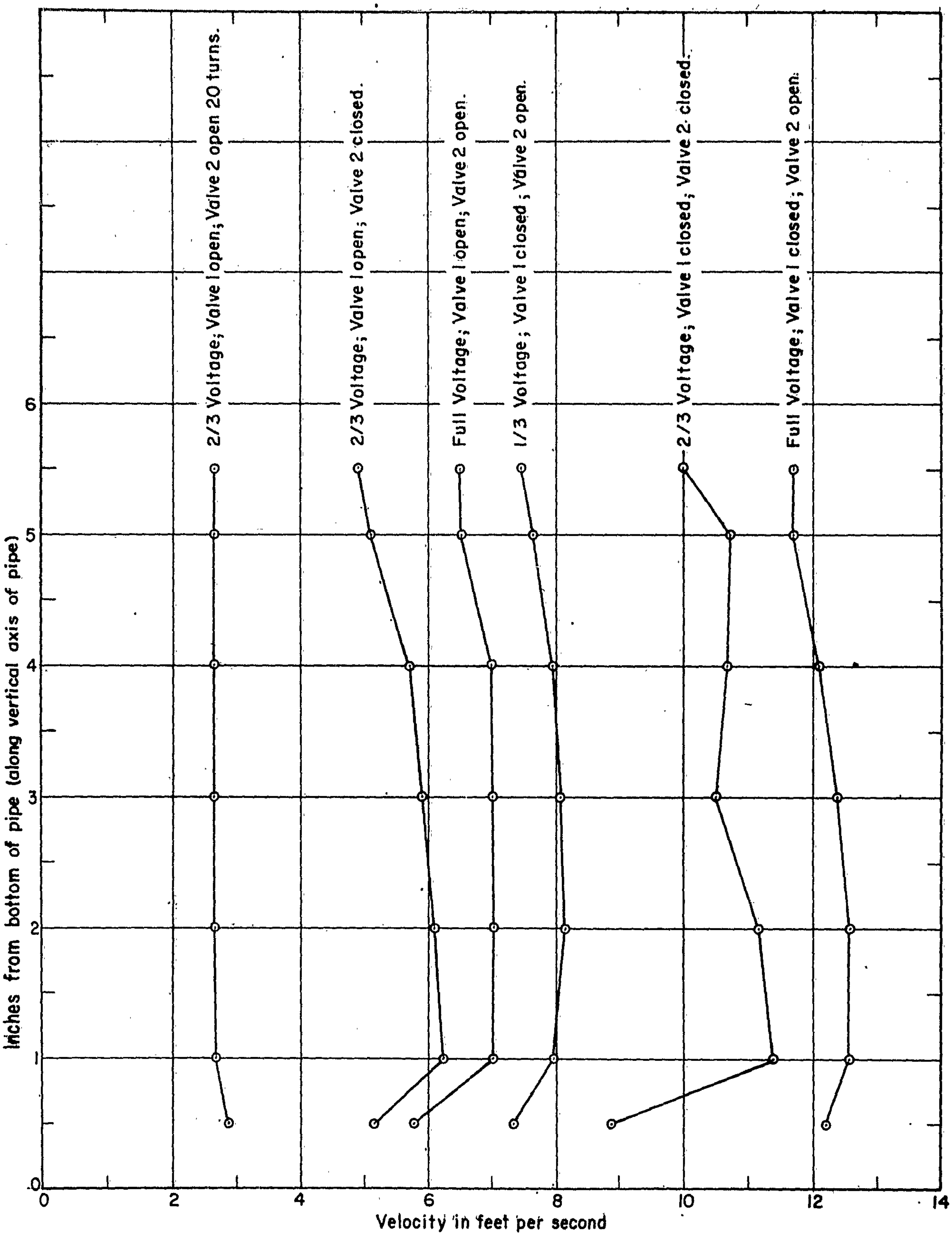
$$V_c = \frac{2500\,\nu}{D}$$

where V_c = critical velocity of fluid in feet per second
ν = kinematic viscosity of fluid, in feet squared per second
D = diameter of pipe, in feet

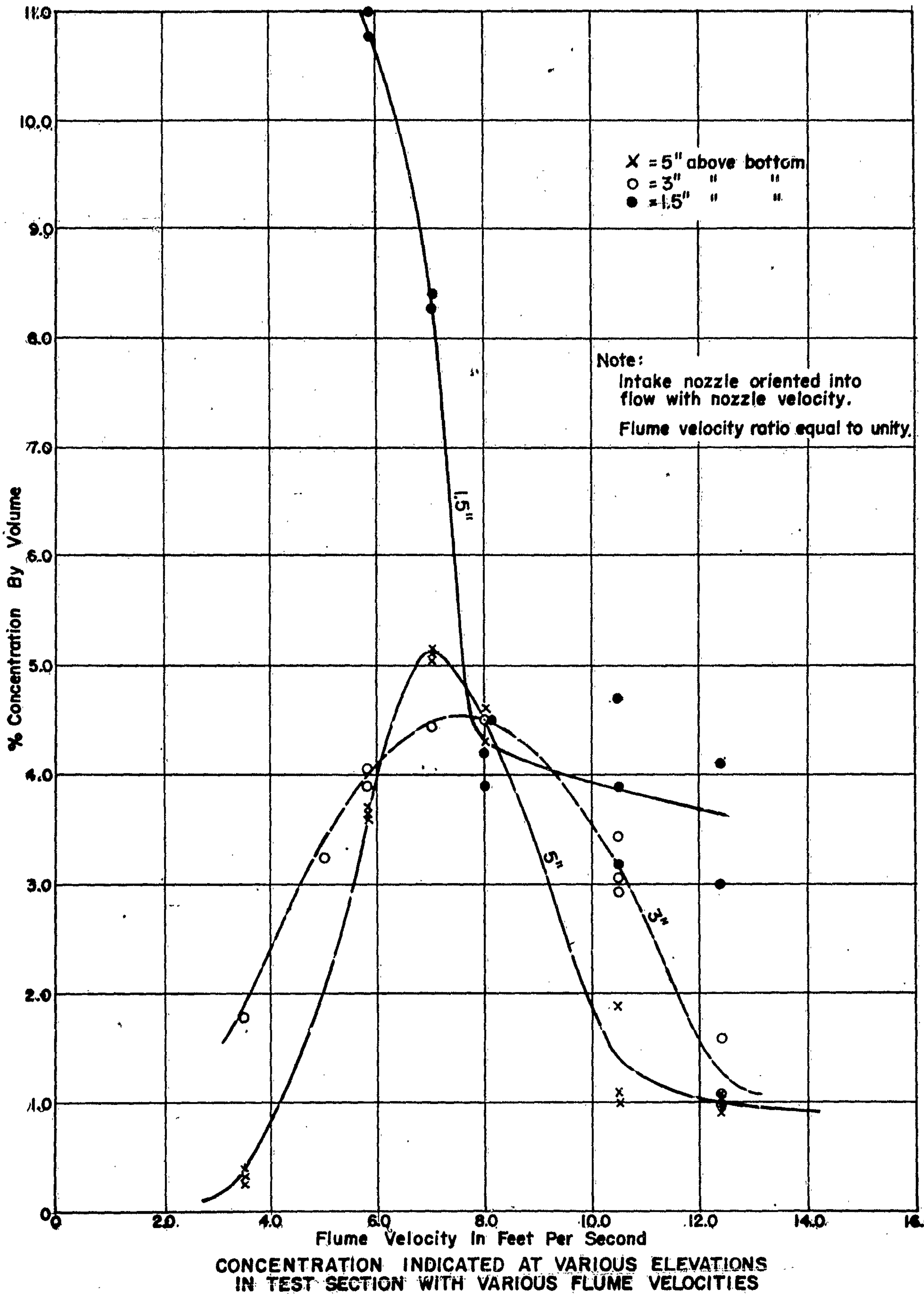
Based on this definition the transition from laminar to turbulent flow would be at velocities less than 0.1 foot per second, which is considerably less than any velocity used in this study. The slight irregularities in the velocity distribution for some of the traverses were probably due to the diversion and pipe bends upstream from the test section.

9. Flume Sediment Concentration - As it was believed that a concentration of 4 percent by volume would be reasonable, the circulating system was adjusted to this concentration. A relatively high concentration in the circulating system was advantageous since when a sample was extracted, the sediment from the sample would be a measurable quantity, thereby eliminating inherent laboratory errors. Knowledge of the volume of water, V_w, the absolute volume of solids (no voids), V_s, the complete volume of the circulating system, V_m, permitted the adjustment of a 4 percent concentration by volume; since $V_m = V_s + V_w$ and $P_{sv} = V_s/V_m$ where P_{sv} is the percentage of solids in the suspension, by volume. As previously stated, a beveled nozzle was utilized to extract reference samples at a flume velocity-intake nozzle velocity ratio of approximately unity. Figure 5 is a plot of data for samples taken, with the reference nozzle at points $1\frac{1}{2}$, 3 and 5 inches from the bottom of the pipe at the test section. This plot illustrates the various changes in concentration that exist at these elevations on the vertical axis for various flume velocity values. The upper limit, or high flume velocity region, was governed by the maximum flume velocity obtainable, which was approximately 12.5 feet per second. Tests indicated that when the flume velocity was reduced below approximately

*) "Applied Fluid Mechanics", O'Brien - Hickox, McGraw-Hill, 1937.



VELOCITY DISTRIBUTION AT SAMPLING STATION
FOR VARIOUS PUMP LOAD - VALVE SETTINGS
FIG. 4



CONCENTRATION INDICATED AT VARIOUS ELEVATIONS IN TEST SECTION WITH VARIOUS FLUME VELOCITIES

FIG. 5

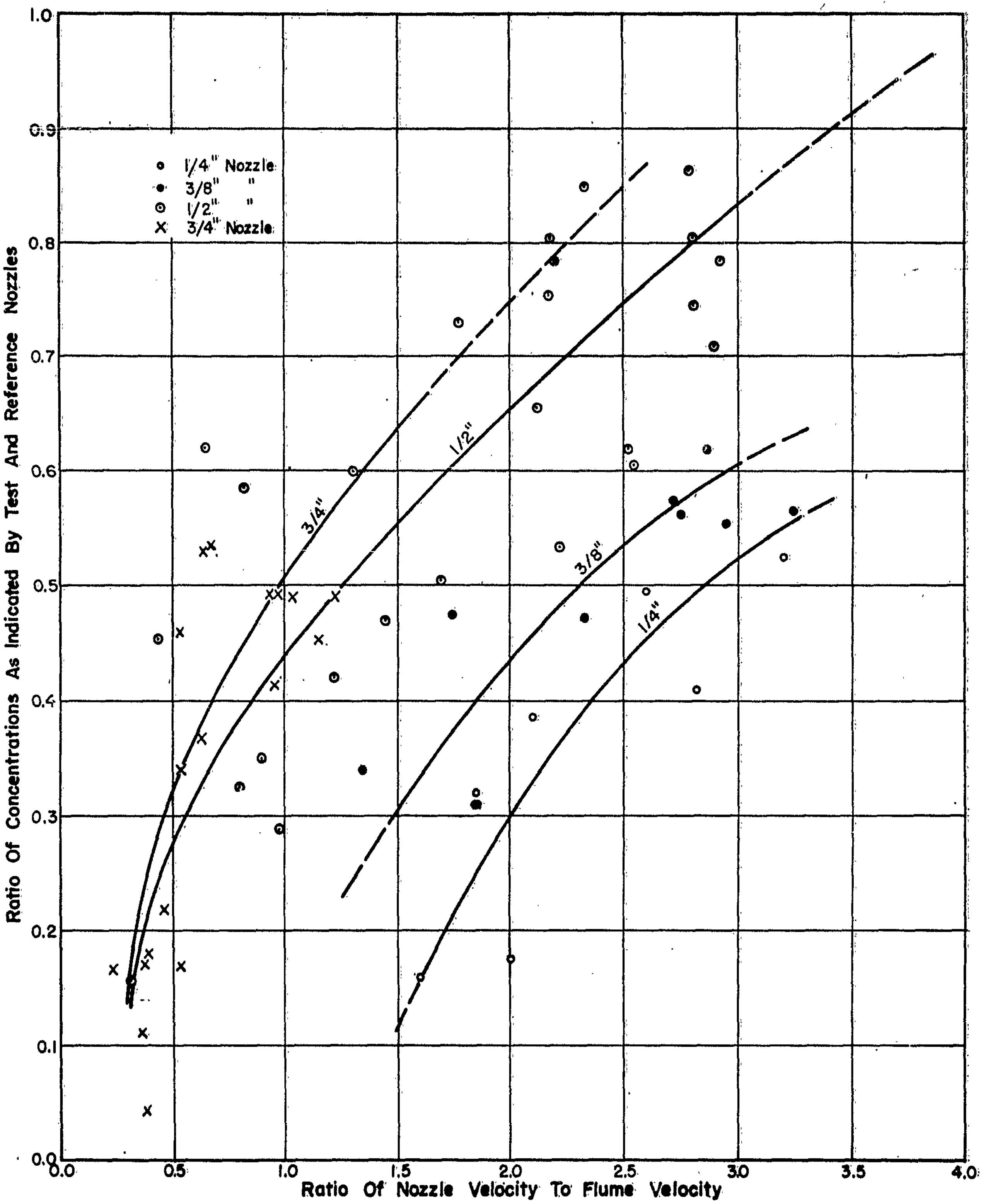
3.5 feet per second, the concentration, particularly at the centerline of the pipe, was extremely erratic and no observations under this condition were used.

10. Pump Sampling Procedure - The schematic view on Figure 2 shows the test or pump intake nozzle for extracting samples from the circulating system at the test section by actual pumping. All sampling was done at the centerline of the pipe in the test section, as data in Figure 5 indicate that a more favorable concentration pattern exists at that point. As previously stated, the test nozzle was always inserted from the top of the pipe with its vertical axis perpendicular to the flow. The data obtained for the plot in Figure 5 served as an index for the concentration actually present at the centerline for various flume velocity values. Samples were taken, by pumping, from the centerline of the test section with a rather wide range of flume velocities and nozzle velocities. To study high and low intake nozzle velocities in relation to the flume velocity, nozzle openings with internal diameters of 1/4, 3/8, 1/2 and 3/4 inch were used. Since the concentration of the suspension at the centerline was known, the accuracy or efficiency of the pump-type sampler could be evaluated. The data obtained for this evaluation consisted of the flume velocity, intake nozzle velocity, concentration of extracted sample, the time involved in sampling. The concentration indicated by the sample taken with the test nozzle was compared to the concentration as determined with the reference nozzle described in paragraph 5. Figure 6 shows sampling efficiency as indicated by the relationship of sediment concentrations for the test and reference nozzles for various ratios of nozzle velocity to flume velocity. The dashed portionsof the curves at the maximum and minimum limits indicate incomplete data for those regions. The limits were governed by the maximum velocities obtainable with the flume pump and the nozzle pump.

11. Size Distribution of Samples - The grain size distribution of samples taken with the test and reference nozzles were compared on the basis of mechanical analysis. The results are shown on Figure 7.

ANALYSIS OF RESULTS

12. Test Section Concentration - The results of the study of concentration distribution at the test section as shown in Figure 5 indicate an unfavorable concentration pattern throughout the cross-section of the pipe for several of the flume velocities utilized. For flume velocities between approximately 7.5 and 9.0 feet per second, the concentration pattern is fairly consistent for elevations 1½, 3, and 5 inches from the bottom. Within these flume velocity limits the maximum variation between samples taken at the three elevations is approximately 18 percent and the minimum variation about 11 percent. The consistency of obtaining samples at any given elevation was approximately $\pm$ 6 percent. As the flume velocity is reduced a wide variation in concentration at the elevations mentioned can be expected since settling of particles will occur causing high concentrations in the lower portion and low concentrations in the upper portion of the pipe. The data and curves confirm

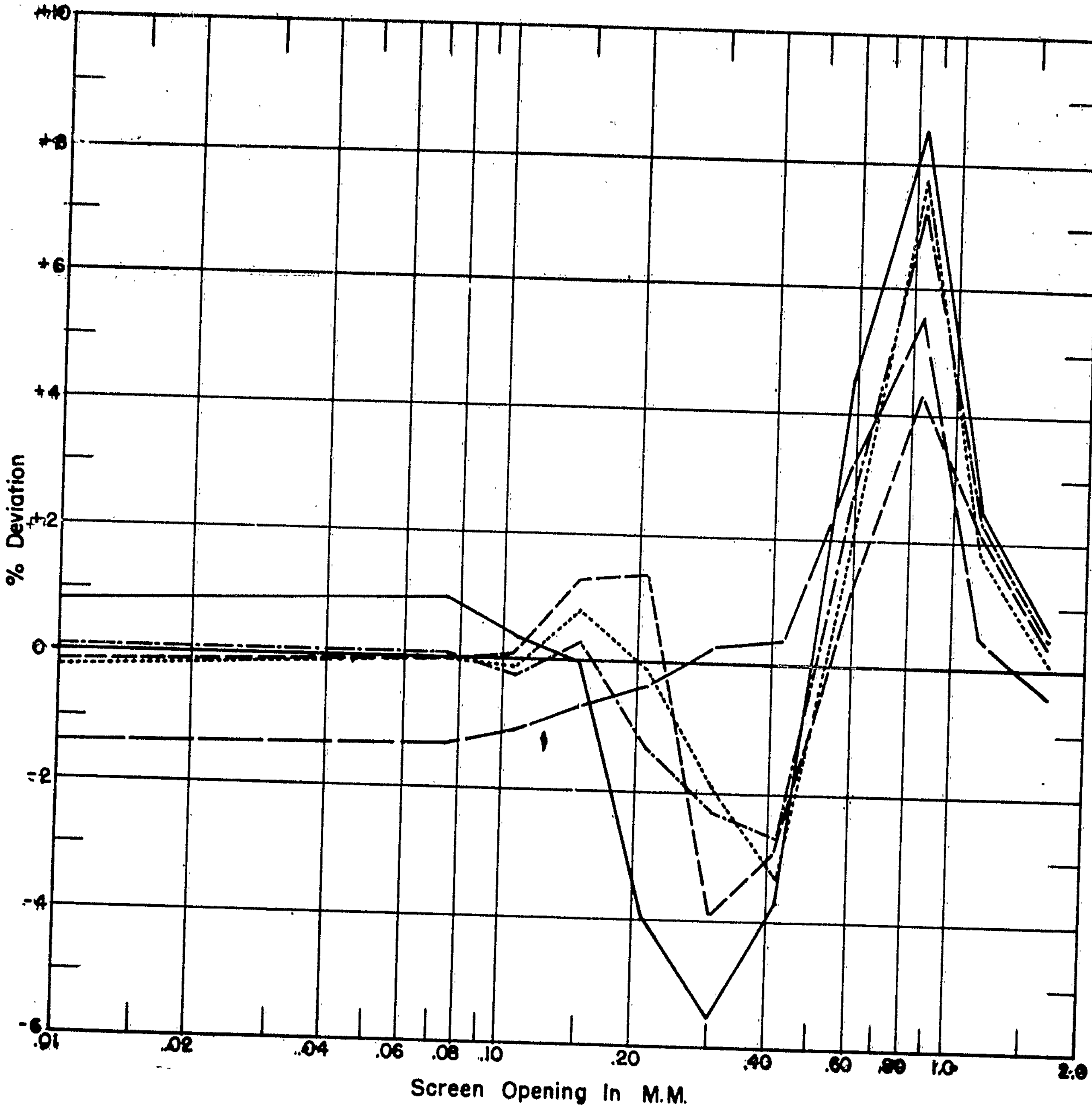


SAMPLING EFFICIENCY
FIG. 6

this expectation. It can be assumed that the data for the 5 and 3-inch elevations would reach a zero concentration at zero flume velocity. For the $1\frac{1}{2}$ inch elevation the concentration increases rapidly once the velocity is reduced to approximately 5 feet per second and with lower velocity values it could be assumed that essentially complete settling of particles had occurred which would result in a high concentration of particles in this region. The concentration data at the three elevations for flume velocities greater than 8 feet per second are not in accord with what would be expected in regular material transportation in pipes, i.e., a relative decrease in concentration to a specific limit with an increase in flume velocity. This decrease of concentration at the various elevations in the test sections is probably due to the diversion and the adjustment of valve 1 upstream from the test section. Maximum velocities in the test section were obtained by applying maximum allowable voltage to the circulating pump motor and completely closing valve 1. When valve 1 had been completely closed, the flow from the diversion point to this valve and thence to the next junction point was virtually zero which allowed material to settle or be trapped in this section of pipe, with consequent reduction of material available for circulation. After the circulating system had been run a reasonable time under these high flume velocity conditions, the consistency of sample concentrations at the centerline of the test section amounted to $\pm$ 8 percent. The sample concentrations for a flume velocity of 12 feet per second at the centerline were some 70 percent less than sample concentrations for flume velocities around 7 feet per second. This appreciable reduction of concentration with increased flume velocities was not desirable, however in light of the results for the consistency of sampling, it was accepted as a satisfactory condition for test or pump sampling.

13. <u>Sampling Efficiency for Various Nozzle Sizes</u> - The curves for the various nozzle sizes in Figure 6 indicate that, for a given ratio of test nozzle velocity to flume velocity, the efficiency or capability of the test nozzle to draw a sample representing the actual concentration, becomes greater as the nozzle size is increased. The maximum nozzle velocity-flume velocity ratio that was possible in these tests was approximately 3 for the 1/4, 3/8, and 1/2-inch size nozzle. A 1.5 ratio was the maximum for the 3/4-inch nozzle. Considering the low maximum ratio possible with the 3/4-inch nozzle, and the maximum grain size (2 millimeters) relative to the 1/4 and 3/8-inch nozzles, it appeared that the 1/2-inch nozzle was the most suitable one for sampling. Although the data are scattered, a systematic trend of increasing efficiency is evident as the nozzle velocity-flume velocity ratio increases. Extension of this curve from 85 percent to approximately 95 percent is dashed and indicates extrapolation.

14. <u>Size Distribution of Samples</u> - Figure 7 shows the deviation of size gradation between samples taken with the reference nozzle and pumped samples. For pumped samples various ratios of nozzle velocity to flume velocity are indicated and the deviation, at any particular size, from the zero line represents the percentage greater or smaller at the indicated



NOZZLE VELOCITY (Ft./Sec.) / FLUME VELOCITY (Ft./Sec.)	=	8.1 / 12.4	= ————
" " "	=	17.7 / 8.02	= —— ——
" " "	=	16.8 / 5.8	= — — —
" " "	=	16.2 / 5.8	= ········
" " "	=	15.3 / 6.98	= —·—·—

DEVIATION OF SEDIMENT PARTICLE SIZE GRADATIONS FOR PUMP SAMPLING AS COMPARED TO SAMPLES TAKEN WITH NOZZLE FACING INTO FLOW, FOR VARIOUS FLUME AND NOZZLE VELOCITIES

FIG. 7

grain size from a sample taken with the reference nozzle facing into flow, the flume velocity and sampling point being the same for both samples. In general the graphs indicate that pumped samples possess a slightly smaller size gradation than they should around the 0.3 millimeter size and slightly larger size gradation than they should around the 0.8 millimeter size, the average magnitude of these deviations being in the order of 3 percent and 5 percent, respectively. As the nozzle velocity was increased relative to the flume velocity there was better size gradation representation in the pumped sample. Furthermore, as the nozzle velocity was reduced relative to the flume velocity a less representative sample as to size gradation was obtained. It was believed that this small percentage deviation in size gradation was well within the limits of acceptability, since in the practical case the nozzle velocity would in general greatly exceed the flume velocity.

DEVELOPMENT OF CORRECTION FACTORS FOR FIELD CONDITIONS

15. Sample Efficiency for Oscillatory Waves - In order to evaluate the efficiency of a pump-type sampler from the information obtained by the laboratory tests, it seemed advisable to assume certain pumping conditions and types of waves, and compute the correction factors which would be applicable. The instant of peak orbital velocity which accompanies the wave crest will also be the instant at which the sampler will pump its least representative sample. The efficiency curve for the 1/2-inch nozzle is shown in Figure 6. This curve indicates that for nozzle velocity-flume velocity ratios greater than 3.5, the nozzle will pump at an efficiency of between 90 and 98 percent. If it be assumed that the sampler will pump with a nozzle velocity of about 18 feet per second, it can then be assumed that the sampler will pump from internal orbital velocities in the wave of from 0 to 5 feet per second at an average efficiency of 94 percent. Therefore, for that part of the wave cycle in which the internal orbital velocities are less than 5 feet per second, a sampling efficiency of 94 percent can be assumed. The sample correction factor, assuming a sampling efficiency of 94 percent would then be 1.06 (the reciprocal of 94 percent). For nozzle velocity-flume velocity ratios less than 3.5 the sampling efficiency falls off rapidly. In view of this condition it becomes necessary to apply an overall correction factor which would in effect allow for the various efficiencies over the wave cycle. Therefore, if measurements are taken outside the breaker zone, it appears possible to evaluate the sampler efficiency as a function of the maximum orbital velocity of the water in the wave. As it is contemplated that most of the sampling will be done in less than 25 feet of water, it will be assumed for the purpose at hand that the maximum orbital velocity is the same from the surface to the bottom and that the velocity sequence is that of simple harmonic motion from zero to the peak velocity at the crest, back through zero, then to the peak velocity in the opposite direction at the trough, and then back to zero. An analysis of waves with peak orbital velocities of from 4 to 16 feet per second --- assuming the wave follows a sine curve and that a pumping velocity of 18 feet per second will be used --- shows that the average sampling efficiency will vary from about 94 percent for

waves with maximum orbital velocities of 4 feet per second to 65 percent for maximum orbital velocities of 16 feet per second. The corresponding sample correction factors are 1.06 and 1.54. The plot on Figure 8 shows the relation between wave period, water depth, and velocity of wave travel. The relationship between the velocity of wave travel and the maximum orbital velocity under the wave crest for various wave heights is shown on Figure 9. The plotted relationships in Figure 9 were computed from the equations below,* and must be considered as first approximations as they do not take into account the deformation of the wave profile which would cause unequal velocities in the upper and lower segments of the elliptical orbit:

$$V = \sqrt{b_s/a_s \; \frac{gL}{2\pi}}$$

$$U_{max} = \frac{gh}{2V}$$

where V = wave velocity

U_{max} = maximum orbital particle velocity

a_s and b_s = semi-major and semi-minor (respectively) axes of the elliptical surface orbits.

g = acceleration due to gravity

L = wave length

h = wave height from trough to crest.

16. The average sample correction factor as shown in Figure 10 was computed by use of the sampling efficiency curve in Figure 6 with the assumption that the concentration at the sampling point was fairly uniform throughout an entire wave cycle and that the internal wave velocities for a wave cycle varied sinusoidally. This is the correction factor which should be used in correcting the weight of the sample. Thus, the determination of the sample correction factors for samples taken outside the breaker zone involve the use of Figures 8 and 9 to determine the maximum orbital velocity of the wave and the use of Figure 10 to determine the average sample correction factor based on this maximum orbital velocity.

17. Sampler Efficiency for Translatory Waves - For the area between the breakerline and the shore line, i.e., the breaker zone, the relationships between wave height, wave depth, and orbital velocity are different than the relationships outside the breaker zone. Inside the breaker zone, the waves tend to act more as translatory waves rather than as oscillatory waves. The wave period is considered to have comparatively little effect

* "A Summary of the Theory of Oscillatory Waves", Beach Erosion Board Technical Report No. 2.

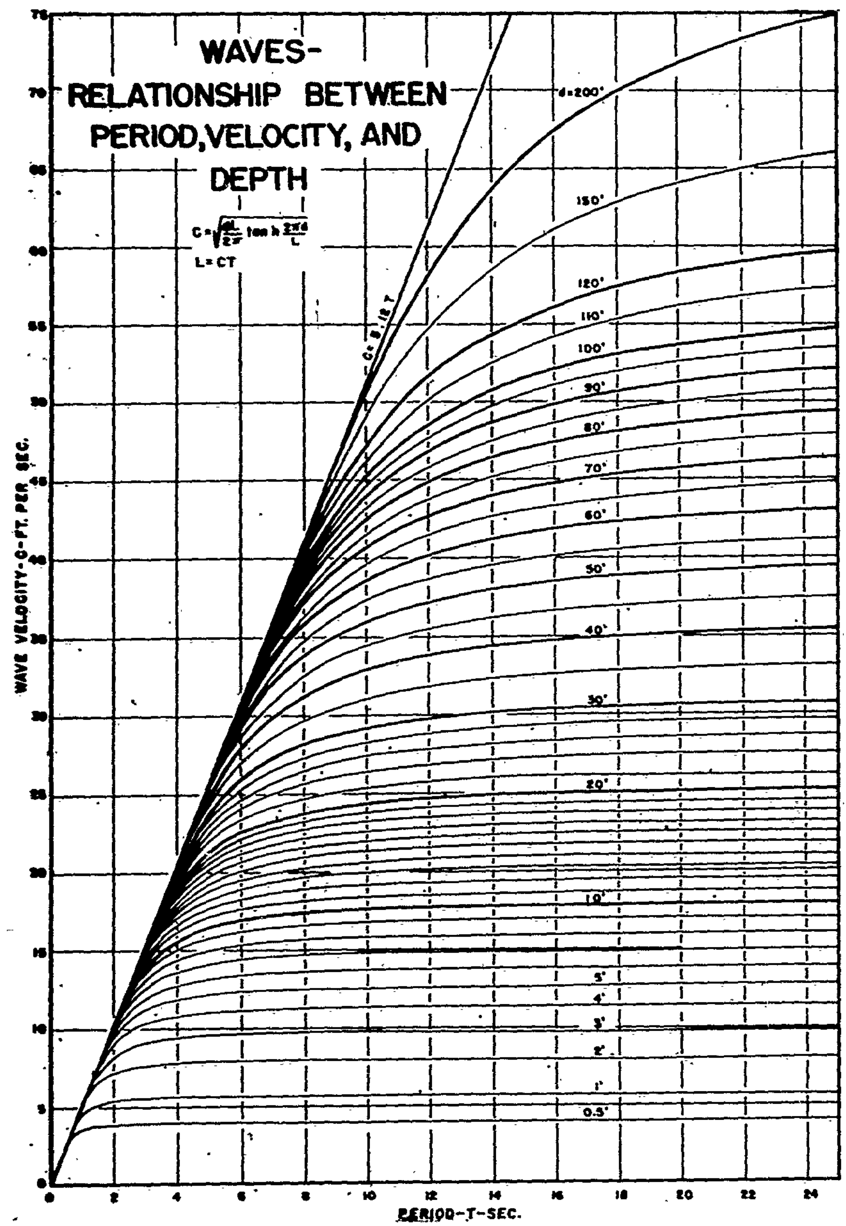
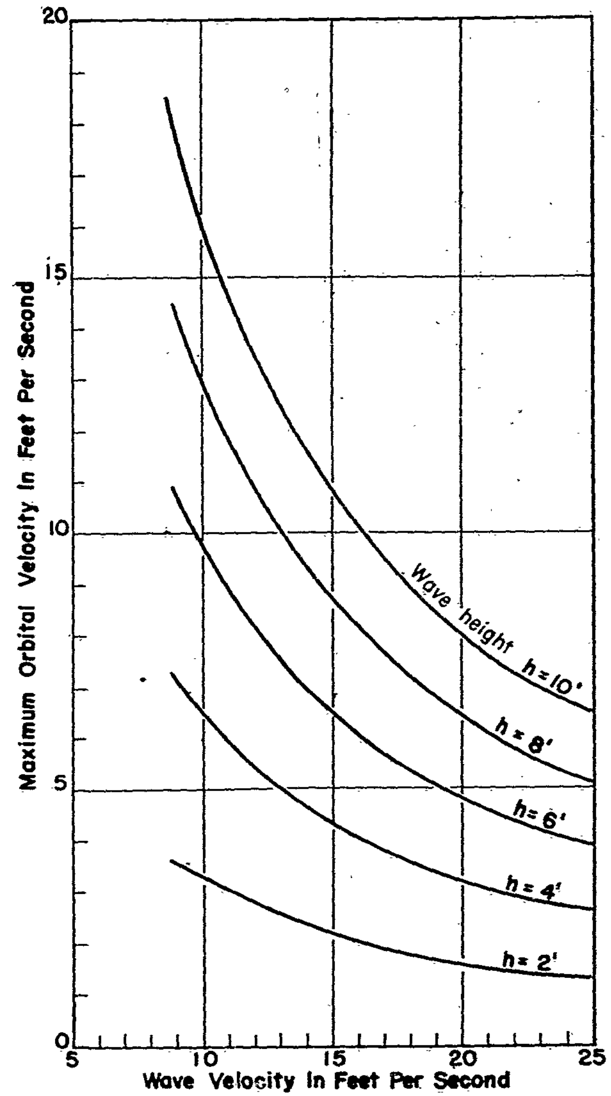
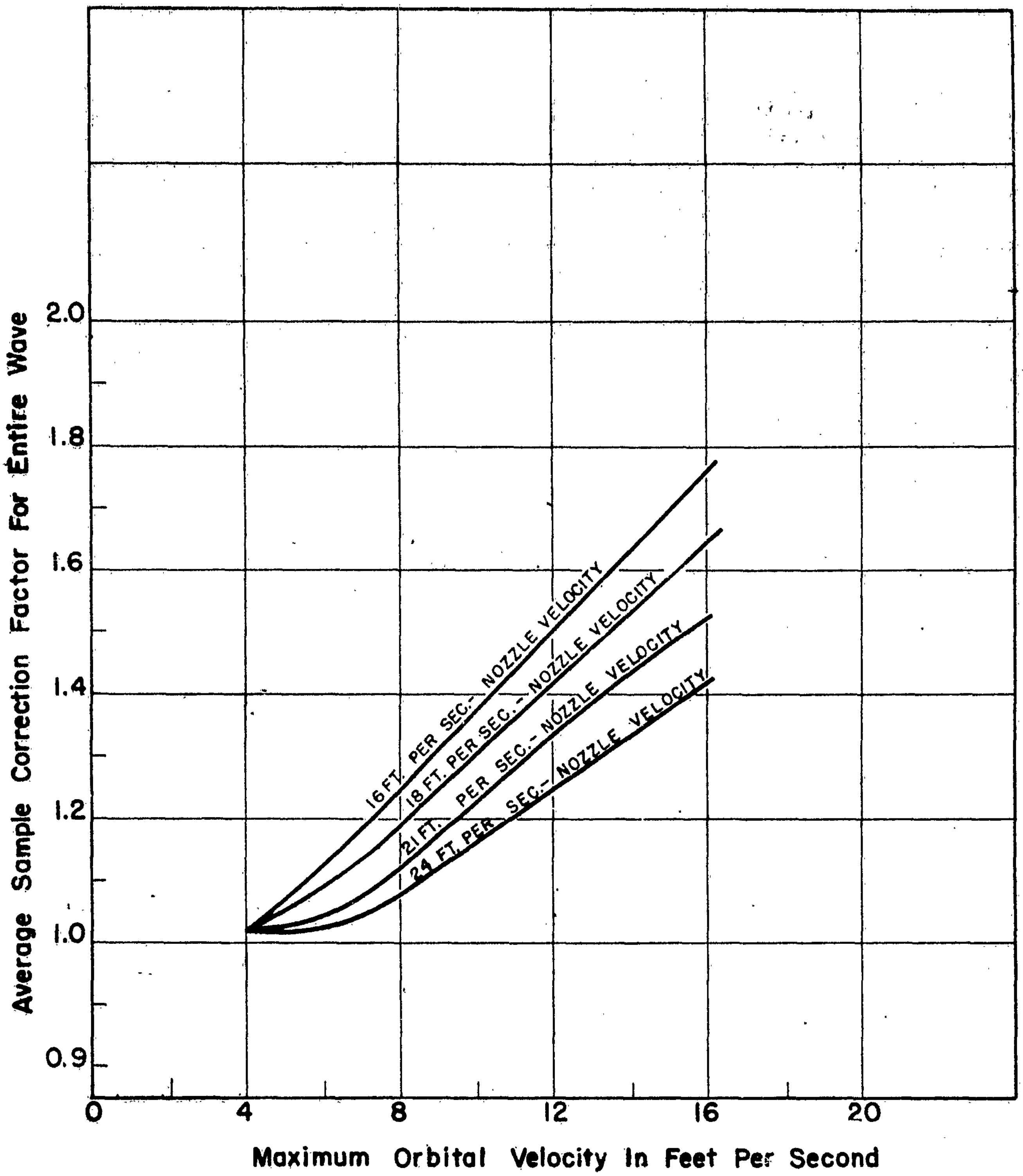


FIG. 8



MAXIMUM ORBITAL VELOCITY
VS.
WAVE VELOCITY
FOR OSCILLATORY WAVES
BEFORE BREAKING
FIG. 9



CORRECTION FACTOR FOR ENTIRE WAVE OUTSIDE BREAKER ZONE

FIG. 10

on the orbital velocities and the solitary wave theory presents probably the best tool for determining the internal water velocities. The sequence of action in the breaker zone appears to be a rather sharp crest accompanied by rather high internal velocities. A series of measurements made in a wave tank at the Beach Erosion Board over a relatively wide range of wave periods and water depths, showed that in the breaker zone the crest occupied an average of 30 percent of the wave length and the trough about 70 percent of the wave length. As the trough particle velocities are as a rule less than 5 feet per second, a sampling efficiency of 94 percent can be assigned to this portion of the cycle. The 94 percent sampling efficiency in the trough must then be combined with the average sampling efficiency during the passage of the crest. The maximum water velocity in the crest can be computed on the basis of the solitary wave theory*. This theory gives the maximum water particle velocity at the crest to be:

$$V_p = V_w \left(\frac{h}{H + h}\right)$$

where V_p = maximum water particle velocity

V_w = velocity of wave travel

h = wave height

H = water depth

For calculating the velocity of wave travel, the solitary wave theory gives:

$$V_w = \sqrt{g\ (H + h)}$$

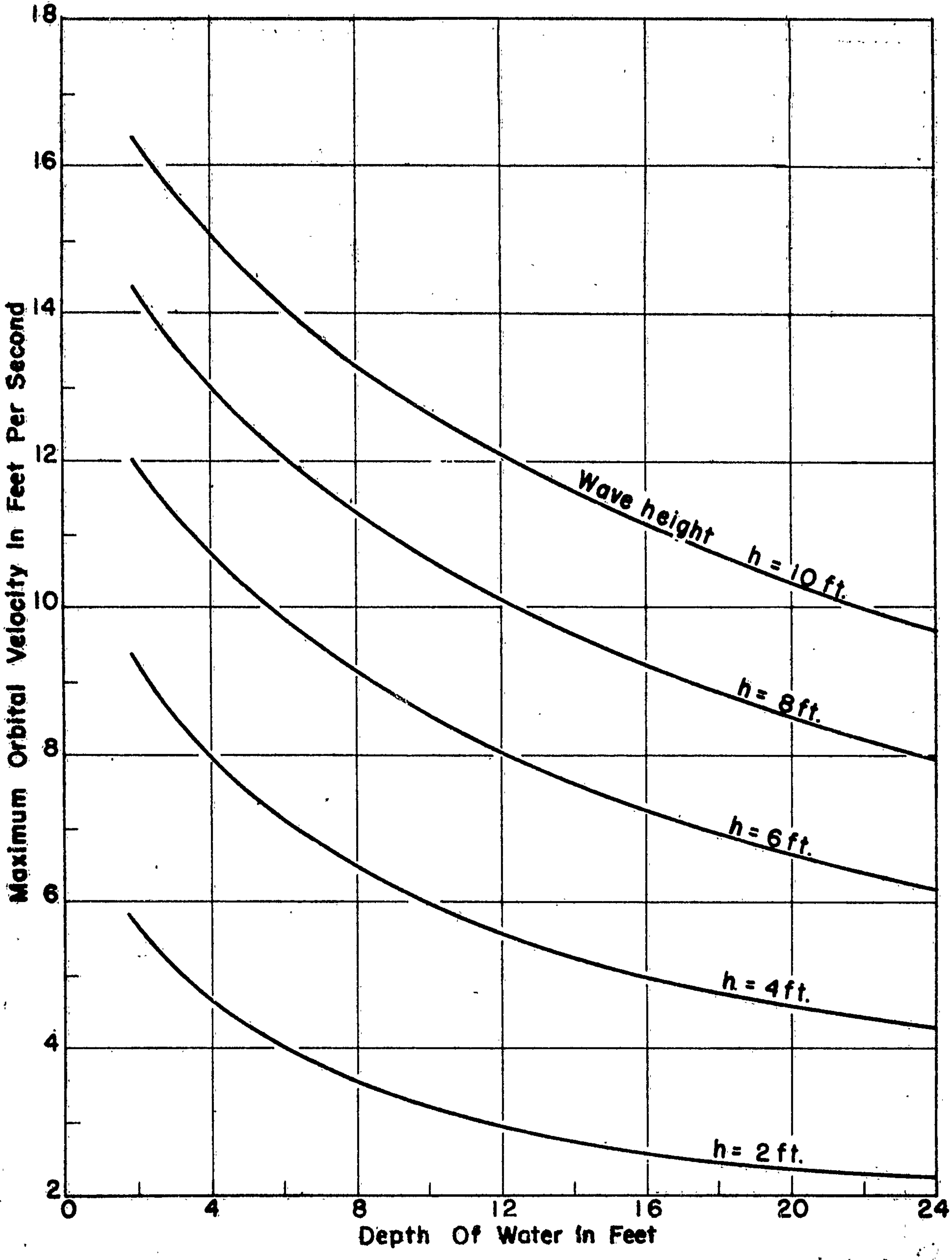
where g = acceleration due to gravity

Combining the above equations we find that:

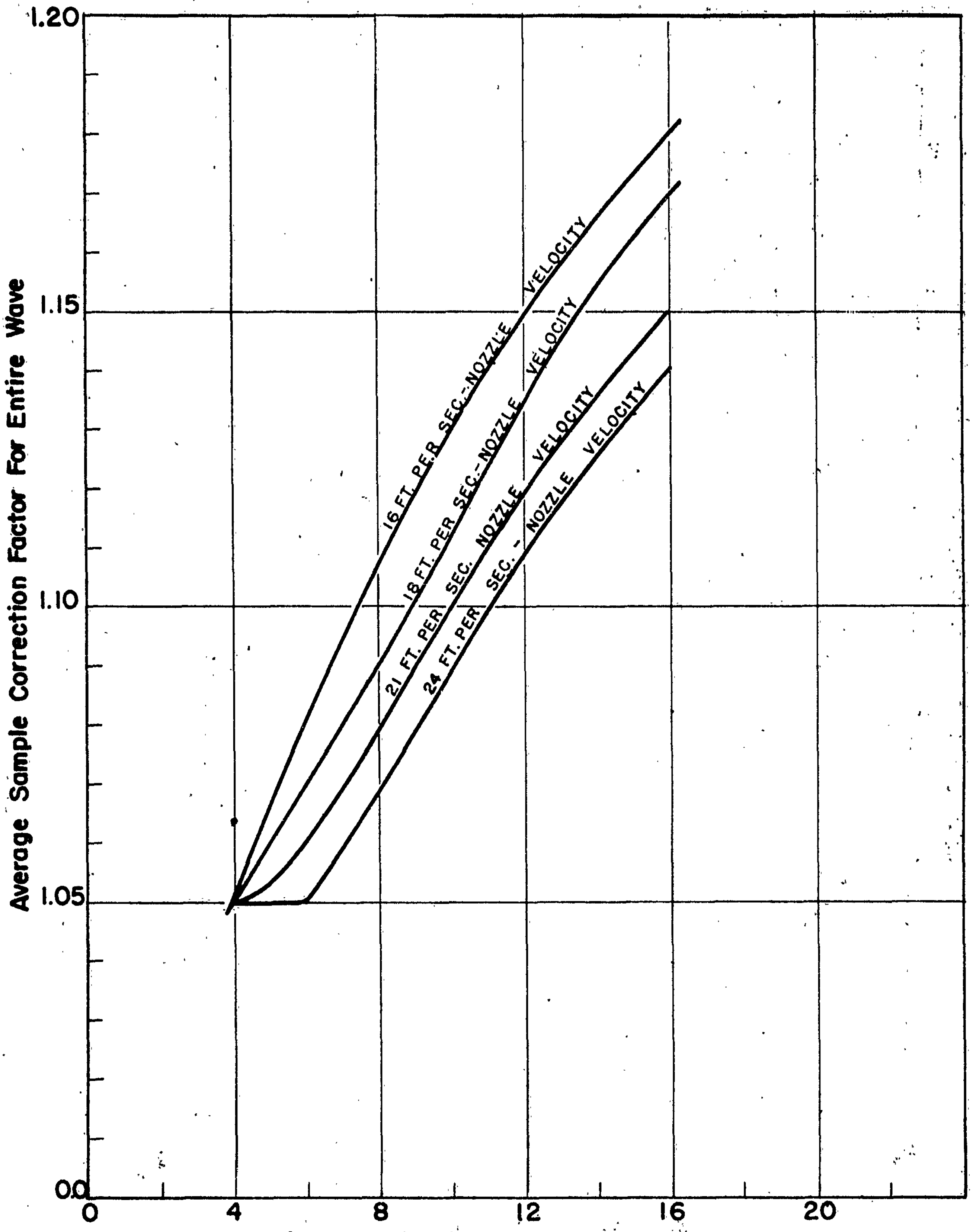
$$V_p = \sqrt{\frac{gh^2}{H + h}}$$

A plot of this equation is given on Figure 11. Since it does not take into account the effect of reflected current upon wave velocity when moving toward a beach, it must be considered as a first approximation of the values under natural conditions, but it serves to define generally the range of maximum particle velocity in terms of water depth and wave height. Once this maximum velocity has been determined, the average sampling efficiency during the passage of the crest portion of the wave can be determined. Assuming that the velocity, during the passage of the crest waves, varies

* "Mathematical Theory of Irrotational Translation Waves", Keulegan, G. H. and Patterson, G. W., Nat. Bur. of Stds. Res. Paper 1272, Jan. 1940.



MAXIMUM ORBITAL VELOCITY
vs.
WATER DEPTH & WAVE HEIGHT
(For waves inside breaker zone)
FIG. 11

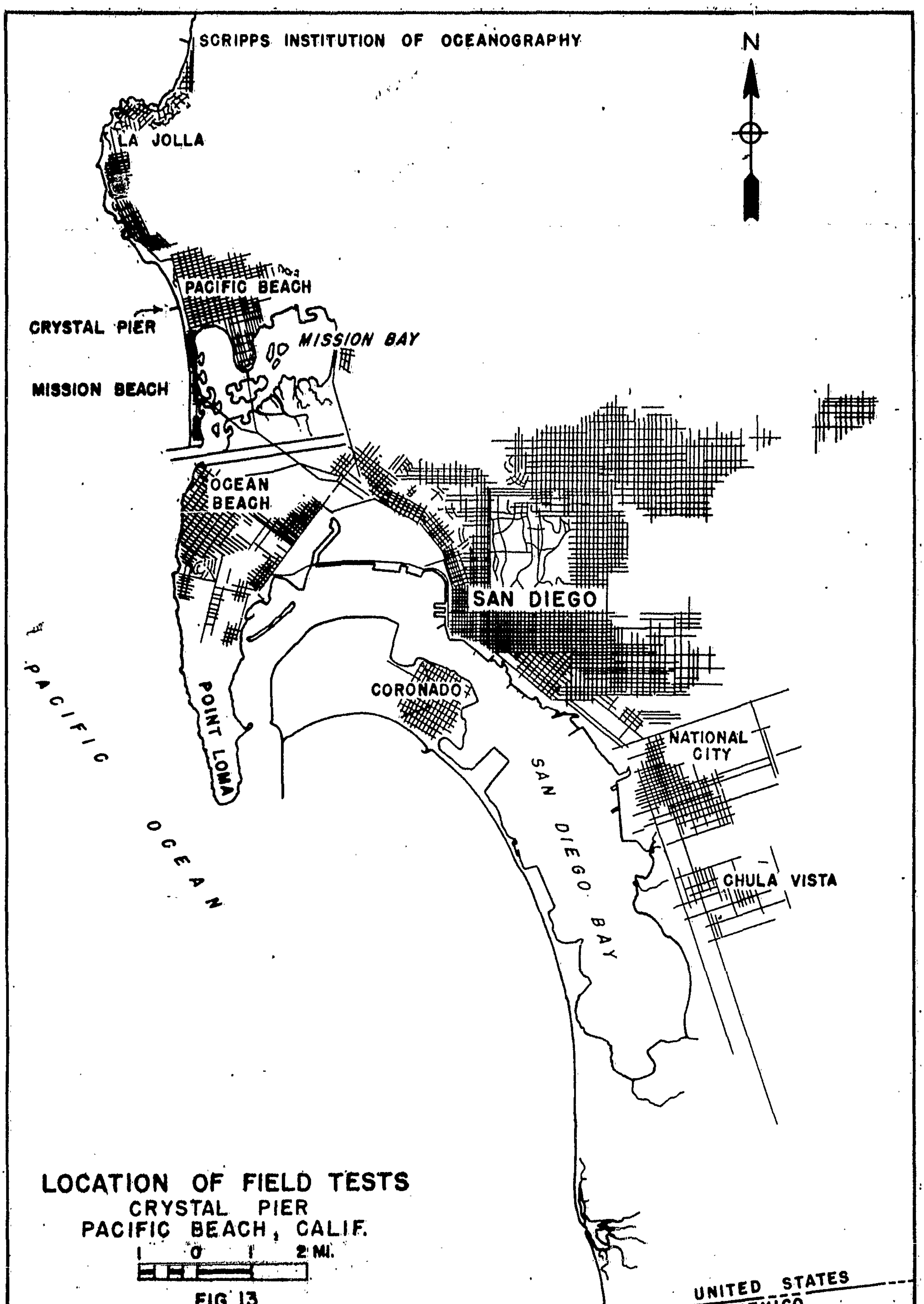


CORRECTION FACTOR FOR ENTIRE WAVE IN BREAKER ZONE
FIG. 12

sinusoidally, the sampling efficiency of the sampler during the passage of the crest can be determined. For the overall sampling efficiency, the efficiency obtained during the passage of the crest portion of the wave must be combined with the average sampling efficiency during the passage of the trough of the wave. As pointed out an average sampling efficiency of 94 percent has been taken as representative of the action in the trough of the wave. As the trough occupies about 70 percent of the wave cycle, the overall efficiency will be weighted between crest and trough efficiency with the 70 percent in mind. Figure 12 has been drawn to show sample correction factors in the breaker zone with the sampler efficiency on the trough weighted 70 times against 30 times for the efficiency during the passage of the crest. It is recognized that this calculation assumes (probably erroneously) that the suspended sand concentration is uniform at the sampling point over the entire wave cycle; however, until more is known of the relative concentration over the wave cycle, this method of correcting the sample appears to be the most reasonable.

CONCLUSIONS

18. The laboratory tests indicate that a pump-type sampler can be adapted to the study of suspended material movement in wave action. The principal result from the tests was a tentative finding that by pumping through a vertically disposed 1/2-inch nozzle with a velocity approximately twice the maximum orbital current velocity in a wave, samples could be obtained which were representative in weight (even without a correction factor) to within about 15 percent of the true suspension. This assumes that the sand concentration at the sampling point is fairly uniform over the wave cycle. The application of the correction factors derived herein permits a reasonable adjustment to be applied to the actual sample weight which compensates somewhat for the inherent error.



LOCATION OF FIELD TESTS
CRYSTAL PIER
PACIFIC BEACH, CALIF.

FIG. 13

PART II - FIELD TESTS

INTRODUCTION

19. Purpose - The laboratory tests discussed in Part I of this report showed that a suspended sediment sampler of the pump type could, if properly designed, be expected to give reasonably accurate measurements of the quantity of the sand thrown into suspension by wave action on a sandy beach. When the Field Research Group of the Beach Erosion Board was making a study of shore line changes in the Mission Bay area, near San Diego, California, from March 1949 to March 1951, opportunity was afforded to make field tests of a suspended sediment sampler designed in accordance with the laboratory findings. The purpose of the field program was threefold, as follows:

a. To test the adaptability of the suspended sediment sampler to use off a pier in open water;

b. To determine the suspended sediment concentration at various points in and immediately outside the surf zone over as wide a range of wave conditions as practicable; and

c. To analyze the results of sampling to obtain an indication of whether or not the suspended load is of sufficient magnitude to play a significant role in the alongshore transport of littoral materials.

20. Description of Area - The Mission Bay area is shown on Figure 13. It lies between the La Jolla and Point Loma headlands. The shore area includes Pacific, Mission and Ocean Beaches. Pacific and Mission Beaches, which appear to be essentially stable, extend southward from the La Jolla headland in a gently curving arc to the jetties at the entrance to Mission Bay. Throughout most of that length the beach is broad and flat with the crest of the beach berm approximately 11 feet above mean lower low water. Seaward from the beach berm the slope is relatively steep, gradually becoming flatter at the approach to the low tide terrace. A low bar is usually present seaward of the terrace.

21. Tidal Data - The tides are of the mixed type with a diurnal inequality. The mean range of tide in this locality is about 3.6 feet, and the mean diurnal range is about 5.2 feet.

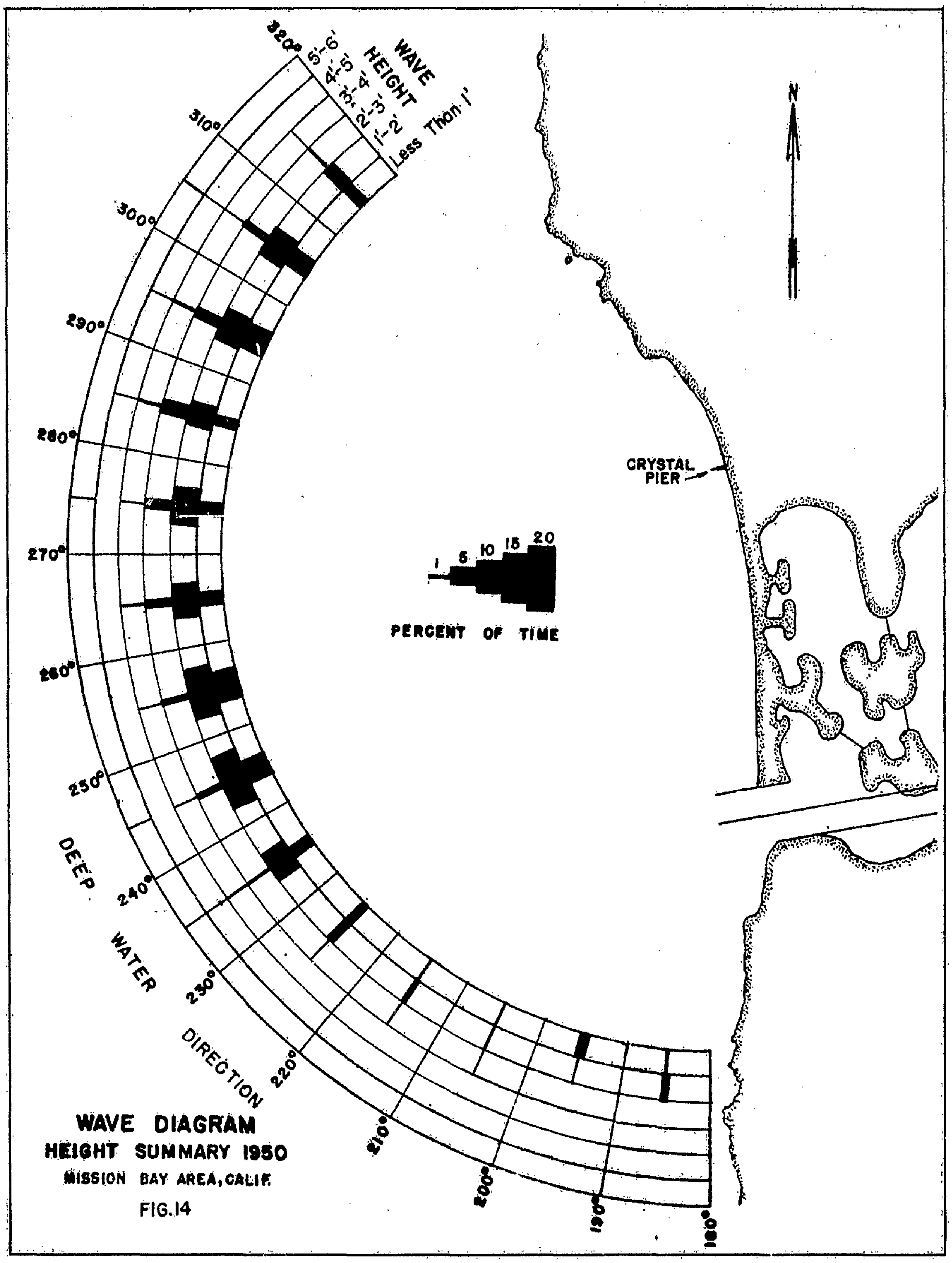
22. Wave Characteristics - From January to December 1950, visual observations were made twice daily of the wave height, period, and direction. During part of 1950 an underwater pressure-type wave gage was operated from Crystal Pier at Pacific Beach. Observed and recorded wave data were supplemented by hindcast wave data using synoptic weather

charts for 6-hour intervals. The results have been compiled into a wave diagram (Figure 14), which presents an estimate of deep water wave conditions for 1950. Because of the lack of weather data for the region south of latitude 15° North, the southern limit of hindcast waves was about 260° azimuth. Also, the northern limit of observed directions was approximately 290° azimuth; waves on the graph with directions north of 290° azimuth were hindcast. Since these latter waves were not observed, it is possible that diffraction around offshore islands altered the direction of waves before they reached Pacific Beach. Thus the sector of wave approach actually observed has as its limits azimuths of 180° and 290°. Percentages of time shown total more than 100 percent since often two or more wave systems occurred simultaneously.

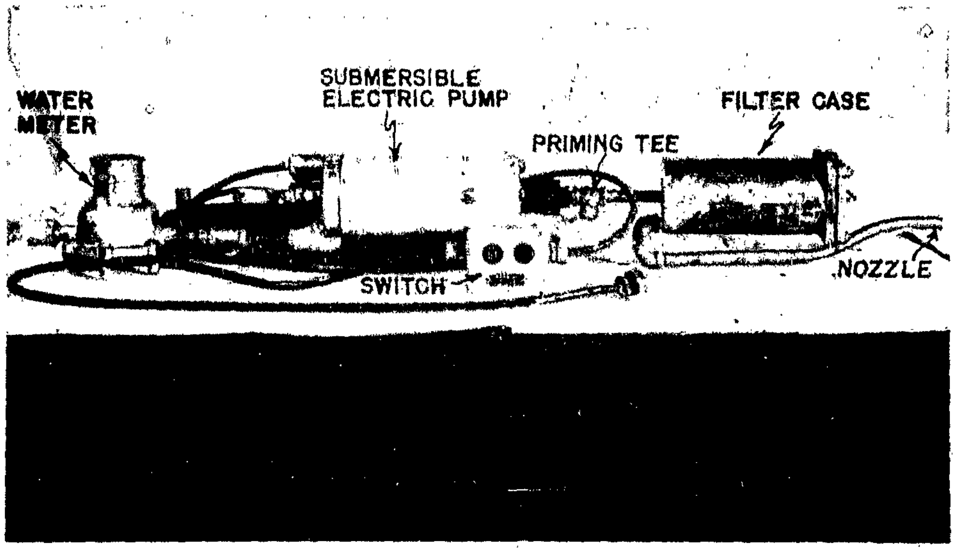
23. <u>Suspended Sediment Sampler</u> - The sampler was designed to gather a sediment sample by pumping a quantity of sediment-laden water from a selected point. The water was discharged back into the ocean after passing through a filter which removed the sediment. The amount of water pumped was measured by a meter connected in series with the filter.

24. The sampler and appurtenances are shown on Figure 15. The apparatus consists of a 1/2-inch intake nozzle, a filter case, a modified filter core, standard check valve, a submersible pump, a standard pipe tee and plug for priming, and a water meter (modified by filling the dial chamber with light oil and replacing the glass face plate with a lucite face plate). The filter paper was 10 ply, Z-fold embossed; the openings in the paper being rated as passing only solids of less than 25 microns diameter. When within 1 to 4 feet of the bottom, the intake nozzle opening was positioned with respect to the ocean bottom by means of a positioning unit which consisted of a round plate attached to the sampler by iron supports. The plate had a spur which penetrated the ocean bottom thereby eliminating any lateral movement of the sampler during operation. The sampling unit was lowered into and removed from the water by means of a block and tackle.

25. The efficiency curve for the sampler equipped with a 1/2-inch diameter intake nozzle was determined from laboratory tests and is shown on Figure 6 (Part I). The sampler was designed to pump with a nozzle velocity of about 18 feet per second. The development tests described in Part I of this report indicate that the sampler will pump at an average sampling efficiency of 94 percent when the internal orbital velocity of the wave is from 0 to 5 feet per second. Therefore, for that part of the wave cycle in which the internal orbital velocity is less than 5 feet per second, a sampling efficiency of 94 percent can be assumed. For nozzle velocity-current velocity ratios less than 3.5 the sampling efficiency falls off rapidly, being only 44 percent when the ratio is unity. In view of these findings a correction factor was developed (Figure 12) which varied with the internal current,velocity in the wave (see paragraphs 15-17, Part I).



WAVE DIAGRAM
HEIGHT SUMMARY 1950
MISSION BAY AREA, CALIF.
FIG. 14



15 a. Component Parts Of Sampler.

15 b. Sampler And Hoist

SUSPENDED SEDIMENT SAMPLER
FIG. 15

FIELD TESTS

26. Procedure - All suspended sediment samples were taken from Crystal Pier, a structure located at Pacific Beach. The pier, shown in an aerial photograph on Figure 17, is approximately 1,000 feet in length. Due to limitations of personnel and time for hydrographic survey work at Mission Bay, the suspended sediment sampling program was conducted only on days of poor visibility, excessively rough seas, or when it was impractical to attempt hydrographic work. Consequently, sampling was done only for a limited number of wave conditions. Samples were taken on 23 days between 15 January 1950 and 15 May 1951. The total number of samples procured was, 290. Samples taken with an intake nozzle velocity less than 15 feet per second were not included in the compilation since these low intake velocities were generally the result of seaweed or debris clogging the nozzle which would greatly influence the accuracy of the indicated sample concentration. Most of the samples were obtained landward of the breaker line since the waves generally broke before reaching the seaward end of the pier. Although 52 samples were obtained seaward of the breaker line, 30 had intake nozzle velocities less than 15 feet per second. The 22 acceptable samples were insufficient in number to make any detailed study in this zone. Of the 238 samples taken landward of the breaker line, 170 were acceptable. A typical field data sheet, Figure 16, illustrates the information recorded for each samples.

27. Pumping Time Per Sample - The influence of pumping time for an individual sample was given careful consideration. It was believed that sampling should be continuous during the passage of at least 15 to 20 wave crests to obtain a representative sample. As noted in the wave summary study there were frequent times when inconsistent or combination wave trains approached the shore thereby creating a rather complex wave period record. However, it appears on the average that a wave period of approximately 13 to 15 seconds prevailed. On this basis it was assumed that a sampling duration of 5 minutes would extract samples of the suspended material from the sea over approximately 15 to 20 wave passages and should provide a representative sample for the prevailing wave characteristics. An analysis of samples taken over a period of approximately 10 minutes indicated a considerable reduction in intake nozzle velocity due generally to the head loss in overloading the sampler filter.

28. Data Obtained - All data obtained on sediment concentrations in individual samples taken landward of the breaker line are given in Table 1. In view of the inaccuracies of estimated wave heights, it was necessary to group the data into classes. The data in Table 1 are grouped by classes of wave heights, water depths and sampling elevations from the bottom. An arithmetical mean concentration is derived for each water depth - sampling elevation - wave height combination.

SUSPENDED SAND DETERMINATION
Crystal Pier
Mission Bay, California

Sample No. 63
Date 7 Mar. 50
Time 1340

Sta. of observation 9+75
Sta. of breaker line 8+50
Sta. of uprush limit 2+50
Sample taken (~~shoreward~~) (seaward) of breaker line.
Estimated wave height at sampling point 2 ft
Estimated wave period at sampling point 15 sec
Water depth at sampling point 11.3 ft
Height of intake nozzle above bottom 9 ft
Duration of run 5 min 0 sec (5.00 min)
Meter reading after run 637.9
Meter reading before run 631.0

Water pumped 6.9 cu ft (x 64.0 =) 442 lbs sea water
Rate of pumping 1.38 cu ft per min
Intake nozzle velocity (cu ft per min x 12.3) 17.0 ft per sec
Max. orb. wave velocity (from curves) 1.7 ft per sec (from ~~recorded~~ estimated wave data)
Correction factor for this sample (from curves) 1.05
Weight of sample less foreign matter, oven-dry 21.6 grams (x 0.0022) 0.0475 lbs
Corrected weight of sample 22.7 grams (x 0.0022) 0.0499 lbs
Parts of sand per thousand parts of water by weight 0.113
Parts of sand per thousand parts of water by volume 0.043
(by weight x 0.379, assuming sp. gr. sand at 2.70 and sea water at 1.025)

Recorded wave height 1.0 ft
Recorded wave period 14.1 sec
Time of wave record 1500
Depth of water at recorder 29.5
Wave direction (observed from shore station) 270°
Time of wave direction observation 1500
Type of breaker Plunging
Littoral drift direction N
Littoral drift velocity 15 ft per min
Time of littoral drift observation 1200
Median grain size of nearest bottom sample 0.165 mm
Sample number of nearest bottom sample 69
Other data on bottom sample
Median grain size of nearest beach sample 0.170 mm
Sample number of nearest beach sample 68
Other data on beach sample
Median grain size of suspended sand sample 0.117 mm
Description of foreign material in sample

REMARKS

FIELD DATA SHEET
FIG. 16

1 FEB. 1951 SCALE 1:5,000

CRYSTAL PIER, PACIFIC BEACH, CALIF.
FIG. 17

TABLE 1 **Concentrations of Individual Samples For Various Combinations of Water Depth - Sampling Elevation - Wave Height Classes**

Water Depth Class (ft)	Sampling Elev. Class (ft. from bottom)	Wave Height Class (ft.)	Concentrations of Individual Samples In Parts Per Thousand by Weight	Arithmetic Mean
2.0 - 3.0	0.6 - 1.0	1.0 - 2.0	0.263	0.263
3.1 - 4.0	0.6 - 1.0	1.0 - 2.0	0.098, 0.142, 0.154, 0.180, 0.183, 0.234, 0.235, 0.266, 0.268, 0.273, 0.287, 0.290, 0.295, 0.318, 0.324, 0.367, 0.399, 0.420, 0.740	0.288
	0.6 - 1.0	3.1 - 4.0	0.651, 1.077	0.864
4.1 - 6.0	0.6 - 1.0	1.0 - 2.0	0.031, 0.086, 0.122, 0.131, 0.163, 0.193, 0.224, 0.225, 0.274, 0.324, 0.352, 0.430, 0.773, 0.867, 1.442, 1.570	0.450
	0.6 - 1.0	3.1 - 4.0	1.460, 1.980, 2.170, 2.340, 2.910, 3.410, 4.430, 4.610, 7.910,	3.47
	1.1 - 2.0	1.0 - 2.0	0.070, 0.072, 0.083, 0.093, 0.168, 0.204, 0.219, 0.237, 0.287, 0.288, 0.329, 0.455, 0.860, 0.874, 0.877	0.341
	2.1 - 3.0	1.0 - 2.0	0.123, 0.429, 0.529	0.360
	3.1 - 4.0	1.0 - 2.0	0.089	0.089
	3.1 - 4.0	4.1 - 6.0	0.808	0.808
6.1 - 8.0	0.6 - 1.0	1.0 - 2.0	0.179, 0.252, 0.416, 0.450, 0.582, 0.646, 1.045	0.510
	0.6 - 1.0	3.1 - 4.0	1.150, 2.500, 2.540, 2.960	2.29
	0.6 - 1.0	4.1 - 6.0	1.374	1.374
	1.1 - 2.0	1.0 - 2.0	0.558, 0.661	0.609
	2.1 - 3.0	1.0 - 2.0	0.194, 0.234, 0.333, 0.524	0.321
	2.1 - 3.0	2.1 - 3.0	0.155, 0.165, 0.171, 0.172, 0.175, 0.177, 0.181, 0.204, 0.206, 0.208, 0.230, 0.232, 0.238, 0.244, 0.247, 0.252, 0.274, 0.316, 0.358, 0.384, 0.482	0.241
	2.1 - 3.0	3.1 - 4.0	0.182, 0.197, 0.240, 0.330, 0.426, 0.427, 0.565, 0.590, 0.736, 1.330	0.502
	3.1 - 4.0	1.0 - 2.0	0.188, 0.244	0.216
	3.1 - 4.0	4.1 - 6.0	1.002, 1.290, 1.310, 1.840	1.36
8.1 - 10.0	0.6 - 1.0	1.0 - 2.0	0.233, 0.272	0.252
	1.1 - 2.0	1.0 - 2.0	0.120, 0.358	0.239
	2.1 - 3.0	1.0 - 2.0	0.026, 0.467	0.246
	2.1 - 3.0	3.1 - 4.0	0.126, 0.152, 0.182, 0.220, 0.221, 0.244, 0.246, 0.257, 0.314, 0.388	0.235
	2.1 - 3.0	4.1 - 6.0	0.324, 0.375, 0.424	0.375
	3.1 - 4.0	1.0 - 2.0	0.149	0.149
	3.1 - 4.0	3.1 - 4.0	0.712, 0.756, 0.908, 1.058, 1.133, 1.140	0.951
	3.1 - 4.0	4.1 - 6.0	0.363, 0.443, 0.471, 0.577, 0.703, 0.715, 0.732	0.572
10.1 - 13.0	0.6 - 1.0	3.1 - 4.0	0.403, 0.541, 0.547, 1.930	0.855
	0.6 - 1.0	4.1 - 6.0	0.244, 0.258, 0.318, 0.604	0.355
	2.1 - 3.0	4.1 - 6.0	0.572	0.572
	3.1 - 4.0	3.1 - 4.0	0.880, 1.196	1.038

PRESENTATION OF DATA

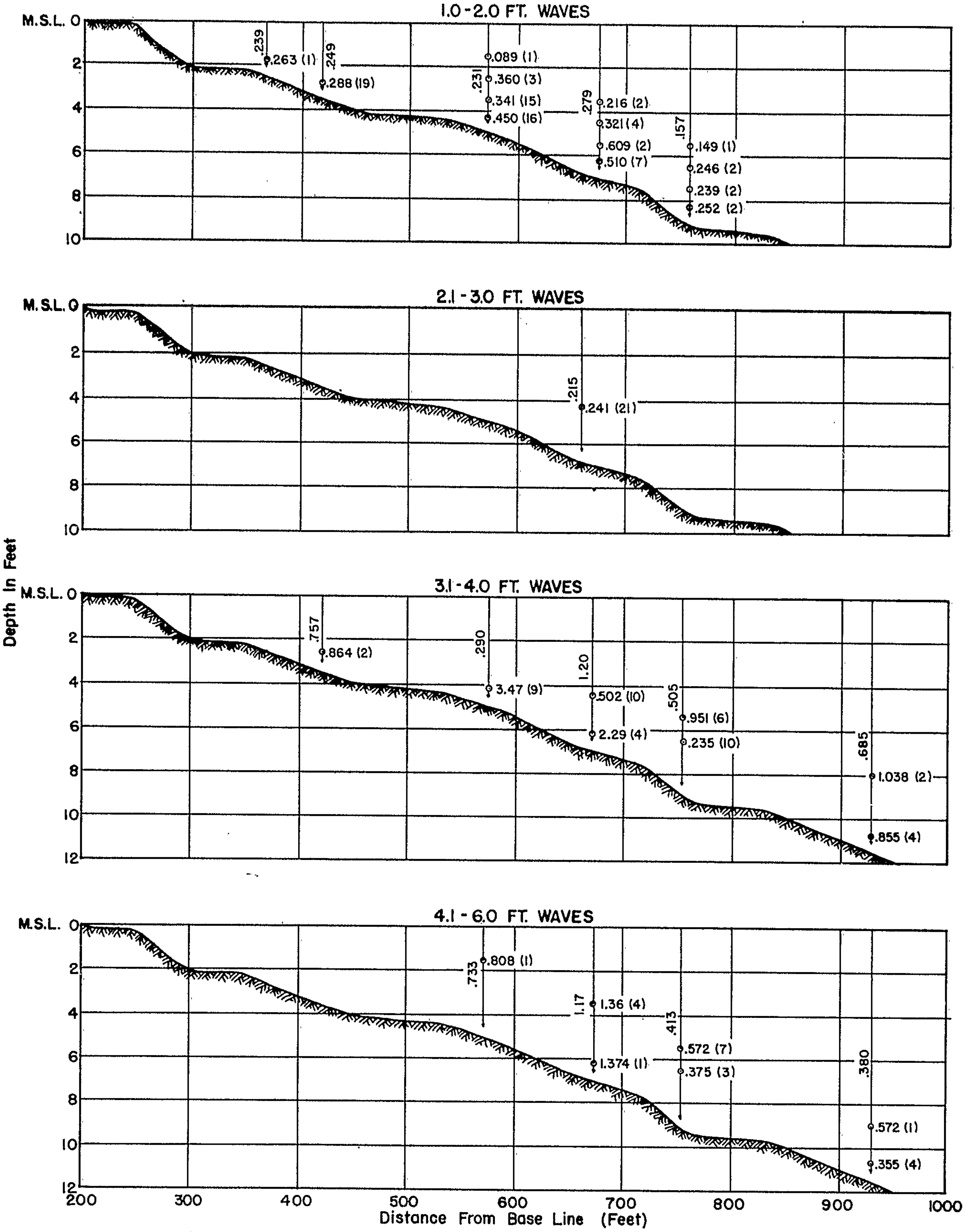
29. Concentration Distributions Along Profile - The mean concentration values from Table 1 were plotted (according to their respective water depth -- sampling elevation -- wave height classes) in relation to a hydrographic profile which is representative of the Crystal Pier location. Figure 18 shows the plotted concentration values for four wave height classes. Where concentration values are indicated at the various depths at a station on Figure 18, an average concentration value for that station also is indicated. This average concentration value for each indicated station was derived by plotting the concentration values between the water surface and 0.5 foot from the bottom, (plots with individual values not shown) then drawing a curve to define the vertical concentration distribution. In establishing the curve, consideration was given to the evidence found in Figure 20 which indicates that the concentration is fairly constant between about two-tenths and six tenths of the depth from the bottom.

30. The average concentration at each station for each wave height class as established in Figure 18 was plotted as shown on Figure 19. These plots of the suspended sediment data represent the average concentration profiles. Curves of visual best fit have been drawn for various wave height classes between the limits of available data. They have been extrapolated thence to the mean sea level shore line and to the 11-foot depth contour for purposes of estimating material movement past the profile.

31. Data for all acceptable samples are given in Table 2 by Z/H ratios and wave height classes; Z being the distance from the bottom to the nozzle intake, and H being the total water depth at the sampling station. The arithmetic means of the concentration values for each wave height class were then plotted against Z/H as shown in Figure 20. These plots represent the vertical concentration profile when all Z/H values are considered for each wave height class.

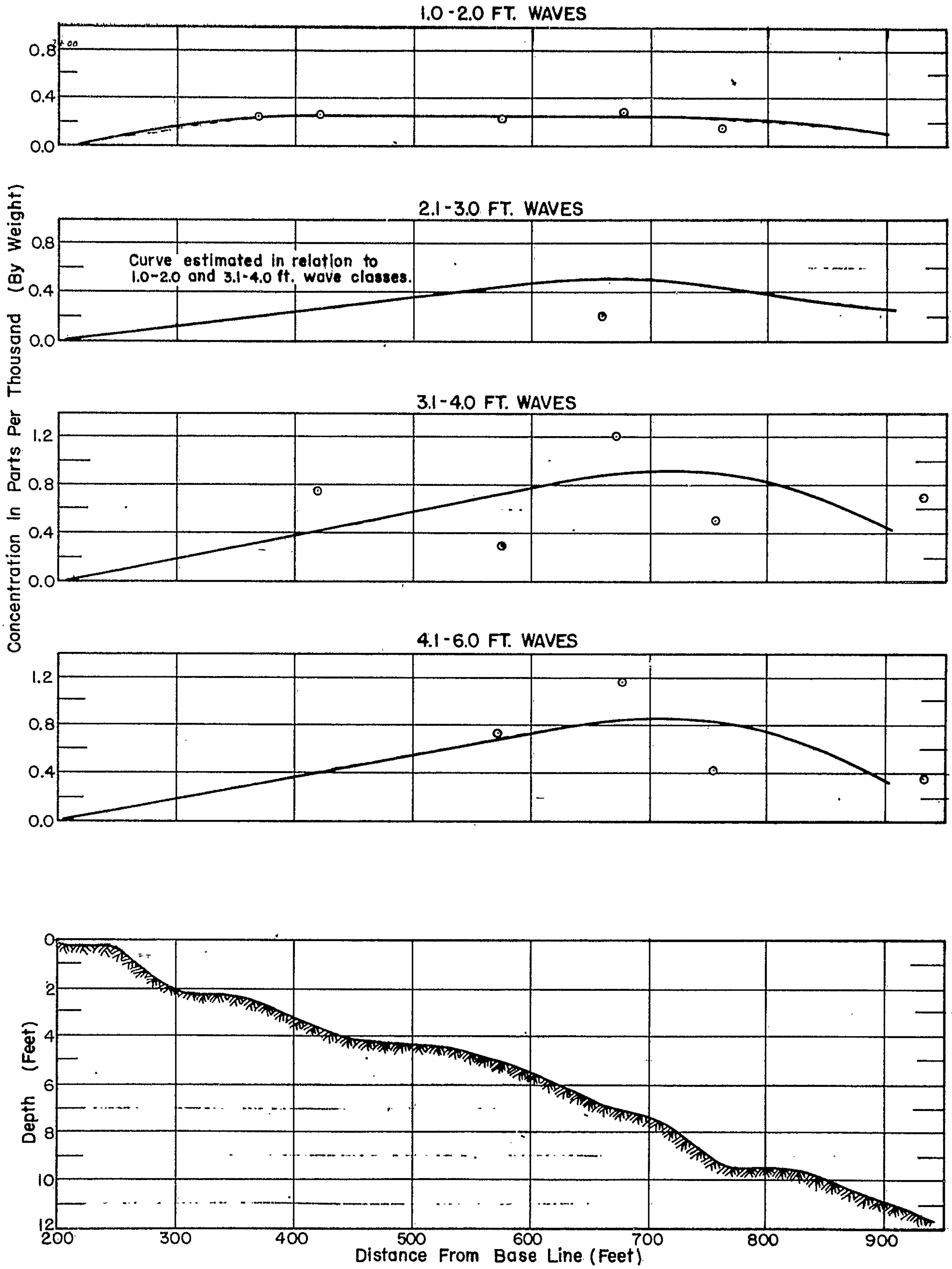
32. Total Material in Suspension - In order to investigate the average concentration distribution shown on Figure 19 in terms of total material in suspension, a tabulation of volumes of sand per linear foot of shore, between the shore and the 10-foot depth (Stations 250 to 850), is presented in Table 3. As can be seen Table 3 utilizes the suspended sediment concentrations, as arrived at from the sampling program, to deduce the average amount of material in suspension in the surf zone, (between the shore and the 10-foot depth contour) for various wave height classes. The volume of material in suspension was computed as $V \rho_w \phi / \rho_s$ where:

- V - Volume of water in cubic yards
- ρ_w - Density of sea water in lbs per cubic yard
- ϕ - Concentration in parts by weight
- ρ_s - Bulk density of sand, taken as 2700 lbs per cubic yard



NOTE: Each point is the average concentration in P.P.T. of all samples taken at that particular water depth and elevation above the bottom. The number in brackets by each concentration value is the number of samples averaged to arrive at the indicated concentration. The average concentration between the water surface and 0.5 ft. from the bottom is indicated at each sampling station. (see fig. 19)

SUSPENDED SEDIMENT CONCENTRATIONS ALONG PROFILE
FIG. 18

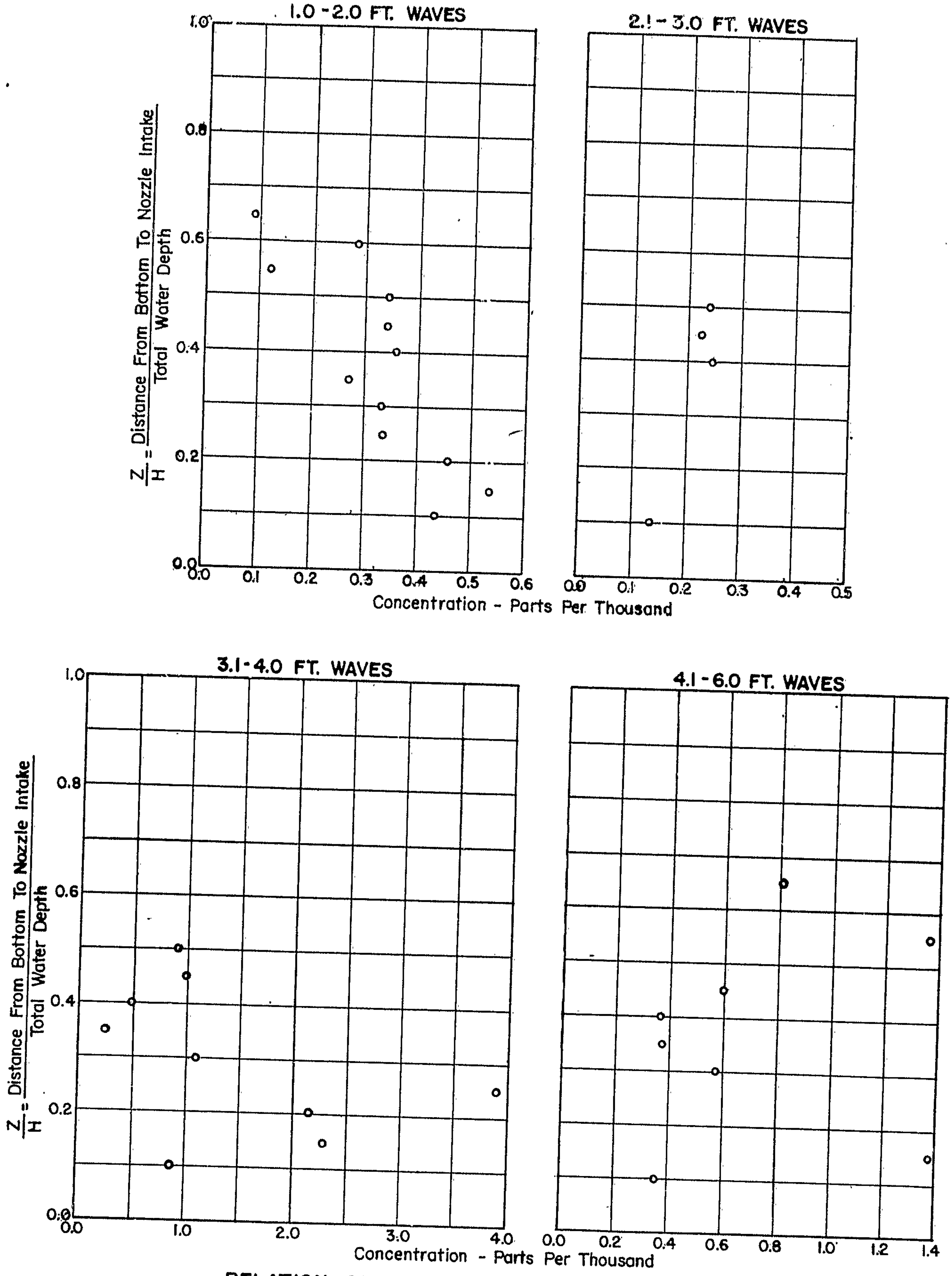


·NOTE: Plotted points indicate average concentrations between the water surface and 0.5 ft. from the bottom. (From fig. 18)

CONCENTRATION DISTRIBUTION ALONG PROFILE
FIG. 19

TABLE 2—SEDIMENT CONCENTRATIONS OF SAMPLES BY Z/H AND WAVE HEIGHT CLASSES
Note: Z = Distance from bottom to nozzle intake; H = Water depth at sampling point; Concentrations in part per thousand by weight

Z/H Class	0.06 to 0.10	0.11 to 0.15	0.16 to 0.20	0.21 to 0.25	0.26 to 0.30	0.31 to 0.35	0.36 to 0.40	0.41 to 0.45	0.46 to 0.50	0.51 to 0.55	0.56 to 0.60	0.61 to 0.65
						1.0 - 2.0 Ft. Wave Class						
	0.233	0.252	0.031	0.120	0.098	0.026	0.083	0.072	0.070	0.123	0.188	0.089
	0.366	0.272	0.086	0.122	0.154	0.142	0.237	0.149	0.093		0.244	
	0.377	0.461	0.163	0.131	0.180	0.168	0.287	0.194	0.204		0.429	
	0.768	0.646	0.179	0.224	0.235	0.183	0.327	0.234	0.288			
	[illegible]	1.045	0.193	0.225	0.290	0.263	0.860	0.333	0.329			
			0.274	0.266	0.318	0.273		0.542	0.529			
			0.324	0.268	0.324	0.455		0.874	0.877			
			0.358	0.287	0.324	0.661						
			0.430	0.295	0.420							
			0.450	0.352	0.558							
			1.442	0.367	0.740							
			1.570	0.399								
				0.773								
				0.867								
Avg	0.436	0.535	0.458	0.335	0.331	0.271	0.359	0.342	0.341	0.123	0.287	0.089
						2.1 - 3.0 Ft. Wave Class						
	0.133						0.149	0.155	0.238			
							0.177	0.165				
							0.206	0.171				
							0.230	0.172				
							0.232	0.175				
							0.244	0.181				
							0.247	0.204				
							0.252	0.208				
							0.274	0.358				
							0.316	0.482				
							0.384					
Avg	0.133						0.246	0.227	0.238			
						3.1 - 4.0 Ft. Wave Class						
	0.403	1.150	1.46	0.651	1.077	0.126	0.152	0.590	0.712			
	0.541	2.50	1.98	2.34		0.182	0.182	0.756	1.058			
	0.547	2.54	2.17	3.41		0.220	0.197	0.908				
	1.93	2.96	2.91	4.433		0.221	0.240	1.130				
				4.61		0.246	0.244	1.140				
				7.91		0.257	0.330	1.33				
						0.314	0.426					
						0.388	0.427					
							0.565					
							0.736					
							0.880					
							1.196					
Avg	0.855	2.288	2.13	3.892	1.077	0.244	0.465	0.976	0.885			
						4.1 - 6.0 Ft. Wave Class						
	0.244	1.374			0.572	0.324	0.042	0.363		1.002		0.808
	0.258					0.375	0.471	0.443		1.29		
	0.318					0.424	0.577	0.703		1.31		
	0.604							0.715		1.84		
								0.732				
Avg	0.356	1.374			0.572	0.374	0.363	0.591		1.361		0.808



RELATION OF AVERAGE SAMPLE CONCENTRATIONS TO PERCENT OF DEPTH. (DATA FROM TABLE 2)

FIG. 20

Although the degree of accuracy of this computation cannot be stated with certainty at this time, it is believed that the amount of material in suspension indicated by these computations is of the correct order of magnitude.

33. Indicated Annual Suspended Littoral Drift.- The next step, shown in Table 4, introduces the yearly percentages of occurrence of the various wave height classes and an assumed net rate of alongshore current to illustrate the net rate of alongshore drift which could be attributed to suspended material (as contrasted to creep, or bed load transport). It is recognized that the assumptions behind these computations are rather broad and it is not intended that these results be accepted for quantitative application to shore erosion studies. However, it is believed that the rate of longshore drift indicated by the computations serves to show that the suspended load is potentially a sizeable factor in the longshore drift picture.

34. Grain Size of Suspended Sediment - Data on the median diameters of a number of samples obtained are given in Table 5. The presentation of data in Table 5 is similar to that in Table 2 with respect to Z/H ratios and wave height classes.

ANALYSIS OF RESULTS

35. Adaptability of Sampler - In this series of tests approximately 71 percent of the total number of samples obtained were employed in studying the suspended material movement. This could be considered as a relatively poor sampling efficiency; however, the sampling efficiency for this particular type of sampler will be a function of the local conditions. In the area where the samples were taken, there was on occasions a considerable amount of eel grass in suspension which clogged the sampler intake nozzle and reduced the intake nozzle velocity so that the sample was of questionable value. The number of acceptable samples would be increased where only a nominal amount of this type of foreign material was in suspension at the sampling point.

36. No satisfactory operational procedure has been developed for this sampler which would facilitate the procurement of samples other than from a fixed structure. The shore structure undoubtedly had some influence on the sample results, but the magnitude of such influence could not be evaluated. Precautions were taken to obtain samples at a point as far from a structural member of the pier as possible, the sampler also being positioned about 10 feet away from the pier. Sampling was done from the side of the pier toward the direction from which waves were approaching.

37. Table 1 shows that when a number of samples were taken with a specific water depth, sampling elevation, and wave height class, the maximum and minimum values of sample concentrations frequently differed

TABLE 3 - MATERIAL IN SUSPENSION PER LINEAR FOOT OF SHORE BY WAVE HEIGHT CLASSES

Station Limits Along Profile	Average Water Depth Within Station Limits	Volume of Water Within Station Limits	WAVE HEIGHT CLASSES 1.0 - 2.0 ft. Avg. Conc.	1.0 - 2.0 ft. Mat'l in Susp.	2.1 - 3.0 ft. Avg. Conc.	2.1 - 3.0 ft. Mat'l in Susp.	3.1 - 4.0 ft. Avg. Conc.	3.1 - 4.0 ft. Mat'l in Susp.	4.1 - 6.0 ft. Avg. Conc.	4.1 - 6.0 ft. Mat'l in Susp.
Ft.	Ft.	Cu. Yds.	P.P.T.	Cu. yds.	P.P.T.	Cu. Yds.	P.P.T.	Cu. yds.	P.P.T.	Cu.Yds.
				$x10^{-4}$		$x10^{-4}$		$x10^{-4}$		$x10^{-4}$
250 - 350	0.9	3.33	0.15	3.2	0.12	2.6	0.19	4.1	0.19	4.1
350 - 450	2.5	9.27	0.23	13.8	0.25	15.0	0.38	22.7	0.38	22.7
450 - 550	4.0	14.80	0.23	22.0	0.35	33.4	0.57	54.4	0.57	54.4
550 - 650	4.8	17.80	0.23	26.4	0.45	51.7	0.79	90.7	0.70	80.4
650 - 750	6.5	24.00	0.23	35.6	0.50	77.4	0.90	139.3	0.85	131.6
750 - 850	8.5	31.40	0.20	40.5	0.39	79.0	0.82	166.1	0.75	151.9
			Totals	141.5		259.1		477.3		445.1

TABLE 4 - INDICATED ANNUAL SUSPENDED LITTORAL DRIFT FOR ASSUMED NET LITTORAL CURRENT VELOCITIES

Velocity of Littoral Current (Assume Direction Constant)	WAVE HEIGHT CLASSES 1.0 - 2.0 ft. Suspended Material Passing Unit Width (%Yearly Occurrence of Wave Ht. Class = 60)	2.1 ë 3.0 ft. Suspended Material Passing Unit Width (%Yearly Occurrence of Wave Ht. Class = 19)	3.1 - 4.0 ft. Suspended Material Passing Unit Width (%Yearly Occurrence of Wave Ht. Class = 4)	4.1 - 6.0 ft. Suspended Material Passing Unit Width (%Yearly Occurrence of Wave Ht. Class = 1.3)	Total Littoral Drift
Ft. Per Min.	Cu. Yds. Per Year	Cu. Yds. Per Year	Cu. Yds. Per Year	Cu. Yds. Per Year	Cu. Yds. Per Year
1	4462	2587	1000	304	8353
5	22310	12935	5000	1520	41765
10	44620	25870	10000	3040	83530
15	66930	38805	15000	4560	125295
20	89240	51740	20000	6080	167060
25	111550	64675	25000	7600	208825
30	133860	77610	30000	9120	250590
40	178480	103480	40000	12160	334120
50	223100	129350	50000	15200	417650
60	267720	155220	60000	18240	502180
70	312340	181090	70000	21280	584710

Note: The percentages of occurrence of wave height classes total 84.3% of time, the remaining percentage comprises time of waves less than 1.0 foot in height.

TABLE 5 - MEDIAN DIAMETERS OF SUSPENDED SEDIMENT SAMPLES

Z/H Class	0.00 to 0.05	0.06 to 0.10	0.11 to 0.15	0.16 to 0.20	0.21 to 0.25	0.26 to 0.30	0.31 to 0.35	0.36 to 0.40	0.41 to 0.45	0.46 to 0.50	0.51 to 0.55	0.56 to 0.60	0.61 to 0.65	0.66 to 0.70	0.71 to 0.75	0.76 to 0.80	0.81 to 0.85
							1.0 - 2.0 Ft. Wave Class										
	0.118	0.116	0.131	0.160	0.136	0.120	0.130	0.120	0.112	0.120	0.162	0.108	0.130	0.138	0.170		0.141
	0.090	0.139	0.113	0.143	0.125	0.150	0.163	0.140	0.130	0.172		0.119					
	0.180	0.145	0.155	0.184	0.093	0.145	0.115	0.152	0.122			0.130					
	0.187	0.100	0.118			0.093	0.118		0.164								
	0.096	0.098	0.112				0.092		0.085								
	0.103	0.097	0.135														
	0.098	0.099	0.150														
	0.099		0.096														
	0.107		0.098														
Avg	0.120	0.113	0.123	0.162	0.118	0.127	0.124	0.137	0.123	0.146	0.162	0.119	0.130	0.138	0.170		0.141
							2.1 - 3.0 Ft. Wave Class										
	0.200	0.120	0.122	0.150	0.141			0.141	0.114	0.170		0.163					0.152
	0.160	0.122			0.143					0.157							0.149
										0.141							
Avg	0.180	0.121	0.122	0.150	0.142			0.141	0.114	0.156		0.163					0.151
							3.1 - 4.0 Ft. Wave Class										
		0.170	0.190	0.200	0.195	0.189	0.170	0.190	0.190								
		0.173		0.160	0.172		0.169		0.170								
Avg		0.172	0.190	0.180	0.184	0.189	0.170	0.190	0.180								
							4.1 - 6.0 Ft. Wave Class										
		0.190	0.184			0.190	0.160	0.185	0.165		0.160						
			0.184				0.160		0.165		0.187						
							0.190		0.190								
Avg		0.190	0.184			0.190	0.170	0.185	0.173		0.174						

by a factor of 3 to 5. This difference is appreciable and serves to show that the suspended concentration pattern, in relation to time, must be exceedingly complex. The spread in concentration values might be expected to become somewhat less if the class limits (water depth, sampling elevation, and wave height) were decreased. However, the following tabulation is presented to illustrate that repetitive sampling (samples taken as often as possible, under essentially identical conditions) seems to indicate a similiar spread in concentration values, therefore the order of magnitude of spread in concentration values for the class limits used could be expected.

TABLE 6 - REPETITIVE SAMPLING DATA

Estimated wave height at sampling point - 3 feet
Water depth at sampling point - 6.8 feet
Height of intake nozzle above bottom - 3 feet

22 Jan 1951, Time	1354	1404	1414	1428	1445	1454	1505
Concentration of Sample (P.P.T. by Wt.)	0.204	0.155	0.175	0.208	0.482	0.171	0.165

Although the concentration values vary appreciably, it is believed that they indicate the range between the limits of which the true value probably lies; the true value probably not being greatly different than the mean of the group.

38. When the mean values of concentration for various depth and wave height classes are plotted as shown in Figure 18, it can be seen that many more samples would be desirable in order to establish the average concentration profile at each station for each wave height class. Nevertheless, the average concentration value computed for each station indicated in Figure 18 seems to provide a logical and reasonable concentration pattern when plotted as shown in Figure 19. Approximately 70 percent of the suspended sediment data falls into the 1.0 to 2.0 and 3.1 to 4.0-foot wave height classes and there seems to be a reasonable correlation in Figure 19 for these wave height classes. The 2.1 to 3.0-foot wave height class contains only one point and this falls slightly above the average concentration for the 1.0 to 2.0-foot wave height class. The line indicating an average concentration profile for this wave height class is undoubtedly questionable, but was sketched in relation to the 1.0 to 2.0 and 3.1 to 4.0-foot classes, for use in the computations in Table 3. The scattered data for the 3.1 to 4.0 foot and 4.1 to 6.0-foot wave classes in Figure 19 do not indicate any significant difference between the average concentration profiles for the two classes. The fact that the 4.1 - 6.0 wave class concentration profile does not indicate greater concentrations is probably due to lack of data.

39. The concentration profiles in Figure 19 indicate that the greatest amount of material, in this area, is thrown into suspension between the 4 and 8-foot depth contours which is the area slightly landward of the breaker line. There is some evidence that the difference

of the average concentration of suspended material at any station between the breaker line and approximately the 2-foot depth is not great; rather it could be more of a uniform concentration of suspended material between these two points. This fact seems to be brought out in the data tabulated in Table 2 and plotted on Figure 20. Here concentration values at all stations on the profile for each wave height class have been plotted against Z/H classes. For each wave height class, this plot tends to indicate that at any station along the profile there is a depth range where the concentration is fairly uniform and since Z/H values are used for all depths, this uniform concentration zone would extend throughout the surf area. For the 1.0 to 2.0-foot wave height class the range of uniform concentration extends from the two-tenths to the six-tenths depth; the 2.1 to 3.0-foot wave height class has an insufficient number of points and the limits of the range cannot be established; for the 3.1 to 4.0 and 4.1 to 6.0-foot wave height classes the lower portion of the range is indicated to be around the three or four-tenths depth, the upper limit cannot be established due to lack of data.

40. Littoral Drift Computations - Although additional samples would have been desirable, the 170 acceptable samples used for this study seem to present a reasonable concentration distribution when the results are resolved into averages. The overall accuracy of the average concentration values cannot be evaluated at this time, therefore the accuracy of the quantitative computations in Tables 3 and 4 cannot be assessed. As far as is known, no other method has been developed to date, that will give any indication as to the magnitude of the concentrations of suspended material in the nearshore zone. The results, as shown in Table 3, indicate that the suspended load is potentially a sizeable factor in the movement of material alongshore.

41. Grain Size of Samples - The data were studied to determine if a correlation between grain size in suspension and distance from the bottom could be established for various wave characteristics. No trend toward any relationship of this type is apparent from the number of observations taken in this study. It appears that many samples must be taken at each station along a profile under a wide variation of wave characteristics in order to establish this relationship. An analysis of the beach and bottom samples at or near Crystal Pier indicates that the beach and offshore bottom sediments can be divided into three size classes. At the intersection of the plane of mean tide level with the beach the median diameter of the sand is about 0.22 millimeter; from this zone to the 20-foot depth the median diameter of the sand is about 0.15 millimeter; and from the 20-foot to the 50-foot depth the median diameter is about 0.10 millimeter. The suspended sediment samples were taken, in general, landward of the 13-foot depth and analysis of all the suspended samples indicates an average median diameter of about 0.14 millimeter, which compares favorably with the 0.15 millimeter sand size found from mean tide to the 20-foot depth contour.

CONCLUSIONS

42. The field tests of the suspended sediment sampler indicate that the number of acceptable samples procurable with the sampler is dependent on local conditions. Where excessive foreign material is present in suspension, it may clog the nozzle and make the sample unusable. It was found that only 71 percent of the total samples procured at Crystal Pier could be employed in evaluating the data. By averaging the data from acceptable samples a reasonably logical correlation between suspended sediment concentration, water depth, and wave height can be made. The results presented for this series of observations are not of a high degree of accuracy but tend to indicate that the total suspended material movement can be an important factor in a littoral drift analysis.